Surface turbulent heat fluxes

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with significant thanks to Carlos Jimenez and Matt McCabe

CERES Science Team Meeting
NASA Langley
7 May 2013

NASA ENERGY AND WATER CYCLE STUDY
NEWS

Global energy cycle

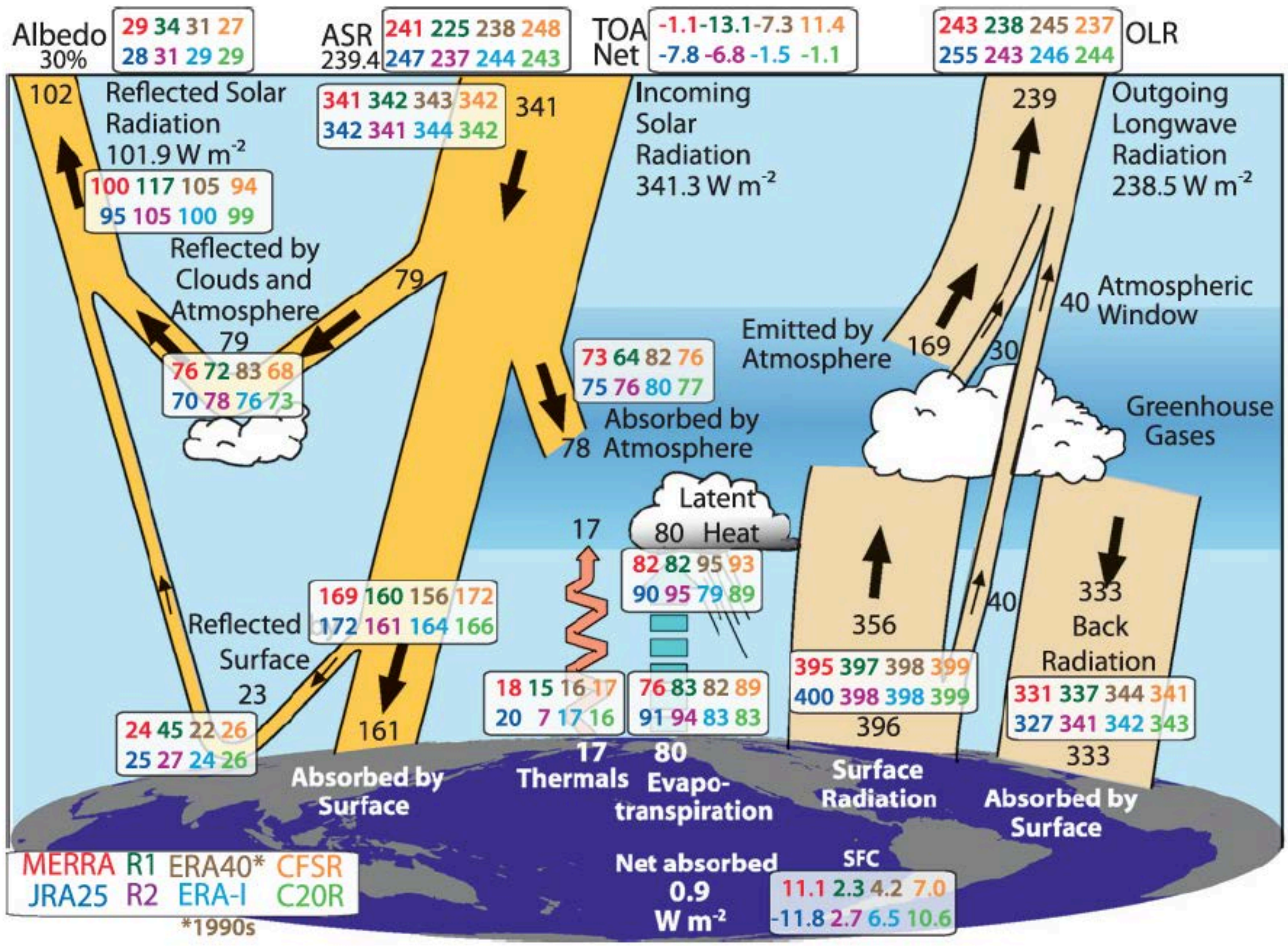
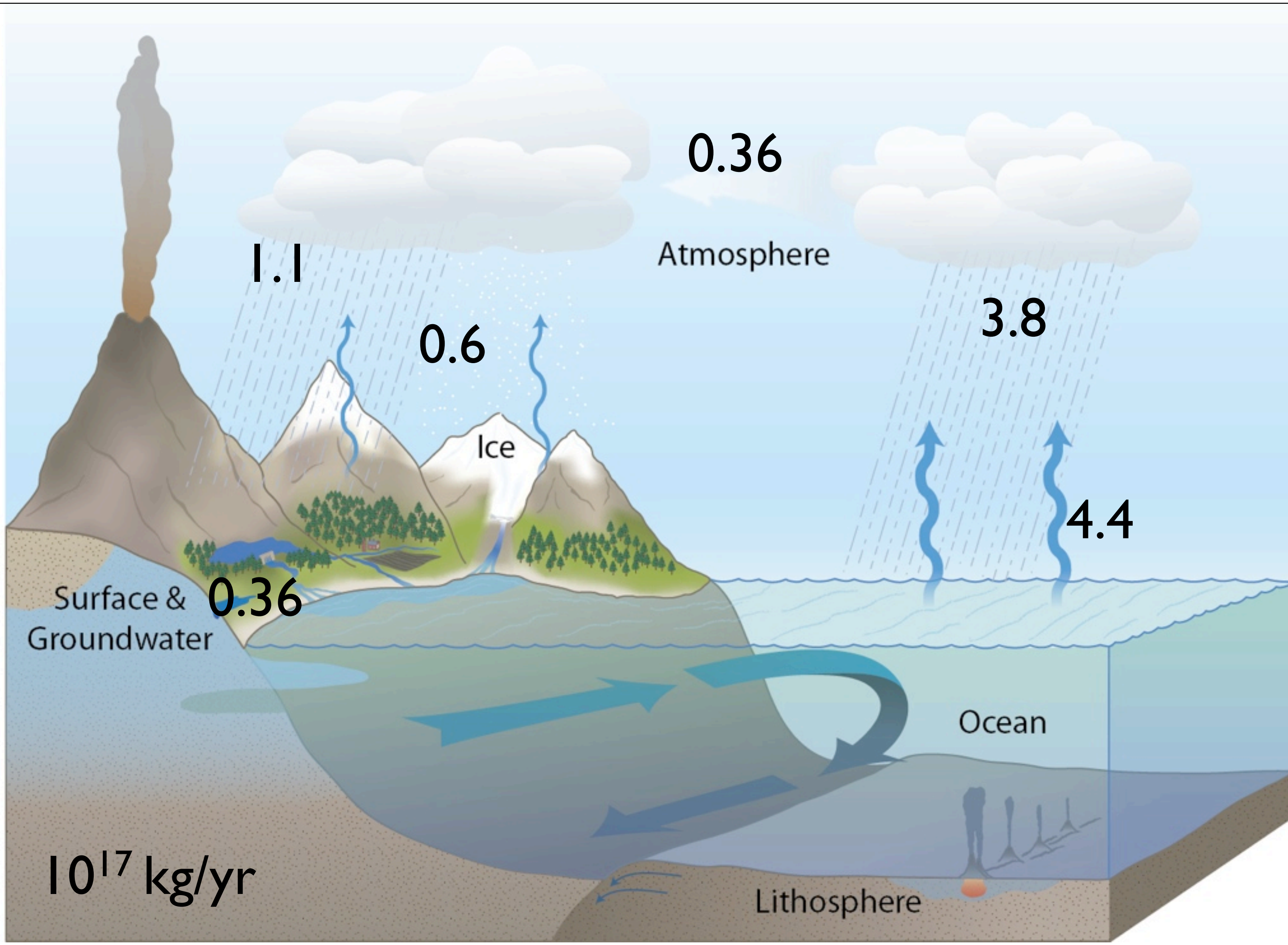


FIG. 10. The background values of radiation or energy flows (Trenberth et al. 2009) are based on observations for 2000–05. Superposed, with the key (lower left), are values from the various reanalyses for the 2002–08 period except for ERA-40, which is for the 1990s (color coded; W m^{-2}). Above the graphic, values are given for albedo (%), ASR, net TOA radiation, and OLR; the box labeled SFC near the bottom gives the net flux absorbed at the surface. For the 1990s the latter value is 0.6 W m^{-2}.

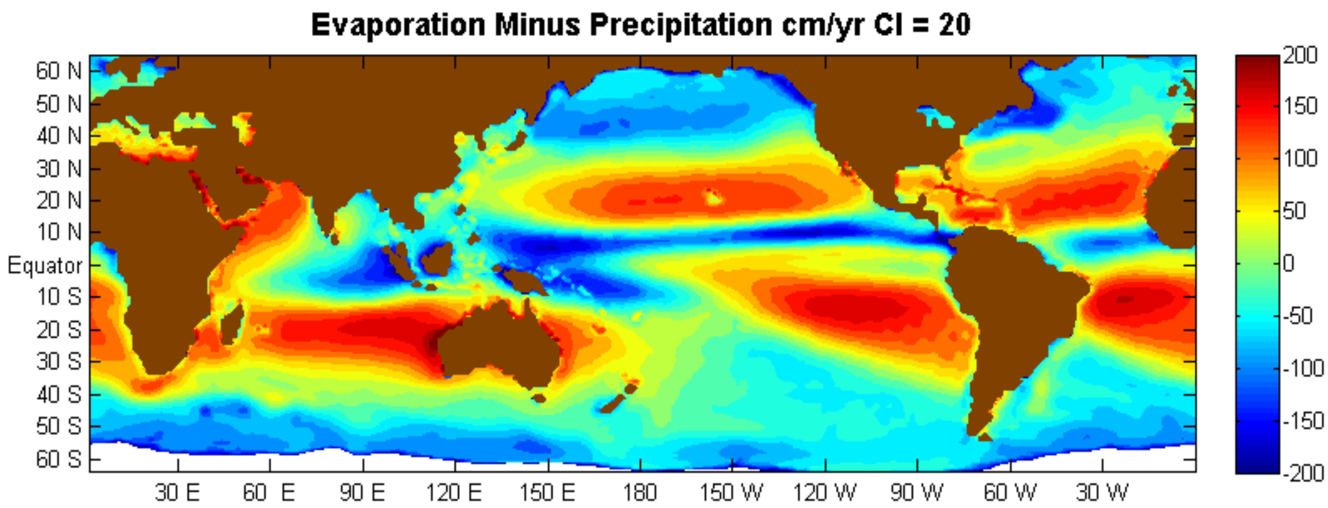
Trenberth et al. 2011

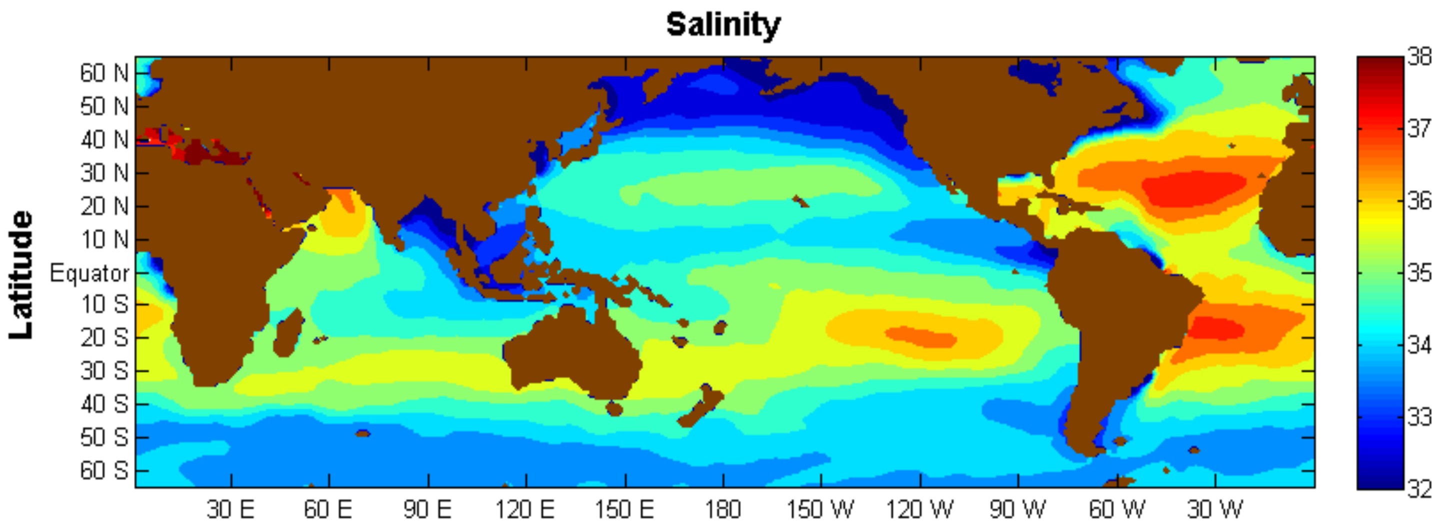


- Evaporative processes play a <u>critical role</u> in the climate system, coupling the surface and the atmosphere and linking the water, energy, and carbon cycles.

The global water cycle

- Primarily an ocean-atmosphere cycle: terrestrial component less than 25% of the mean cycle



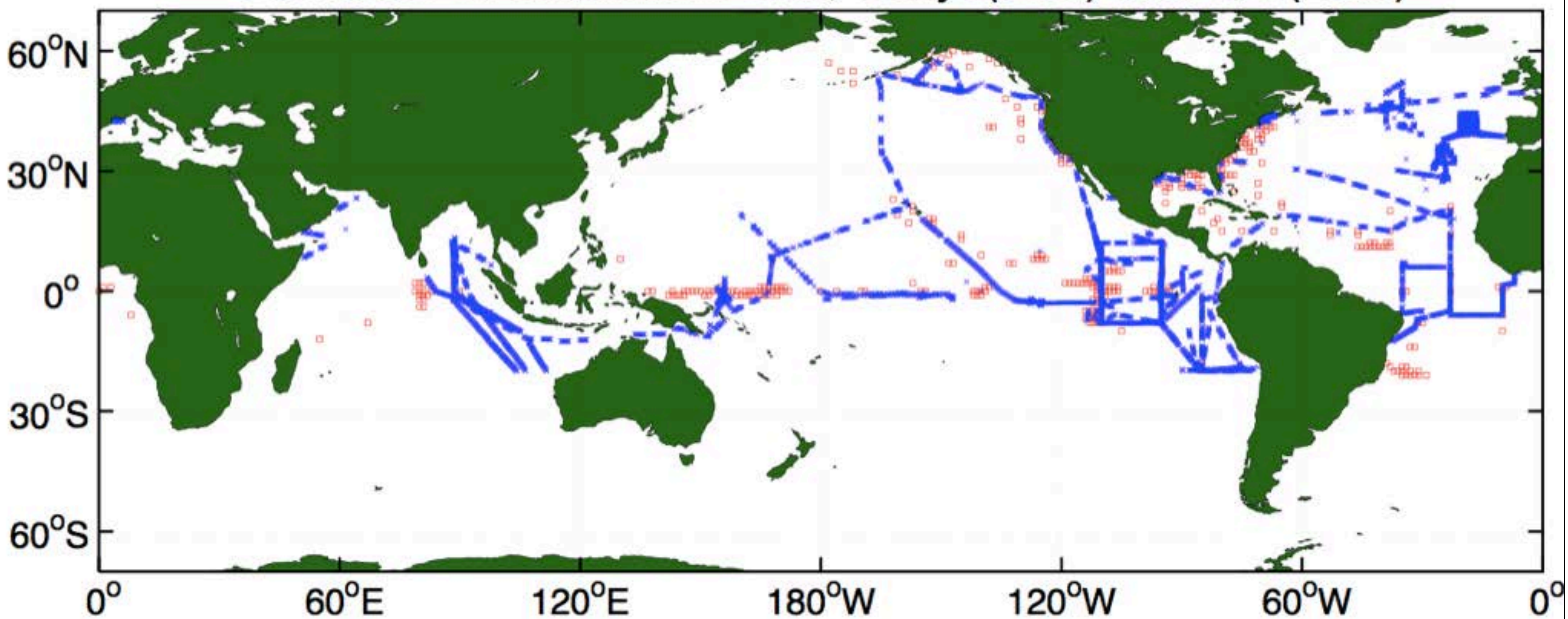


Schmitt 2010

In-situ measured fluxes: not enough

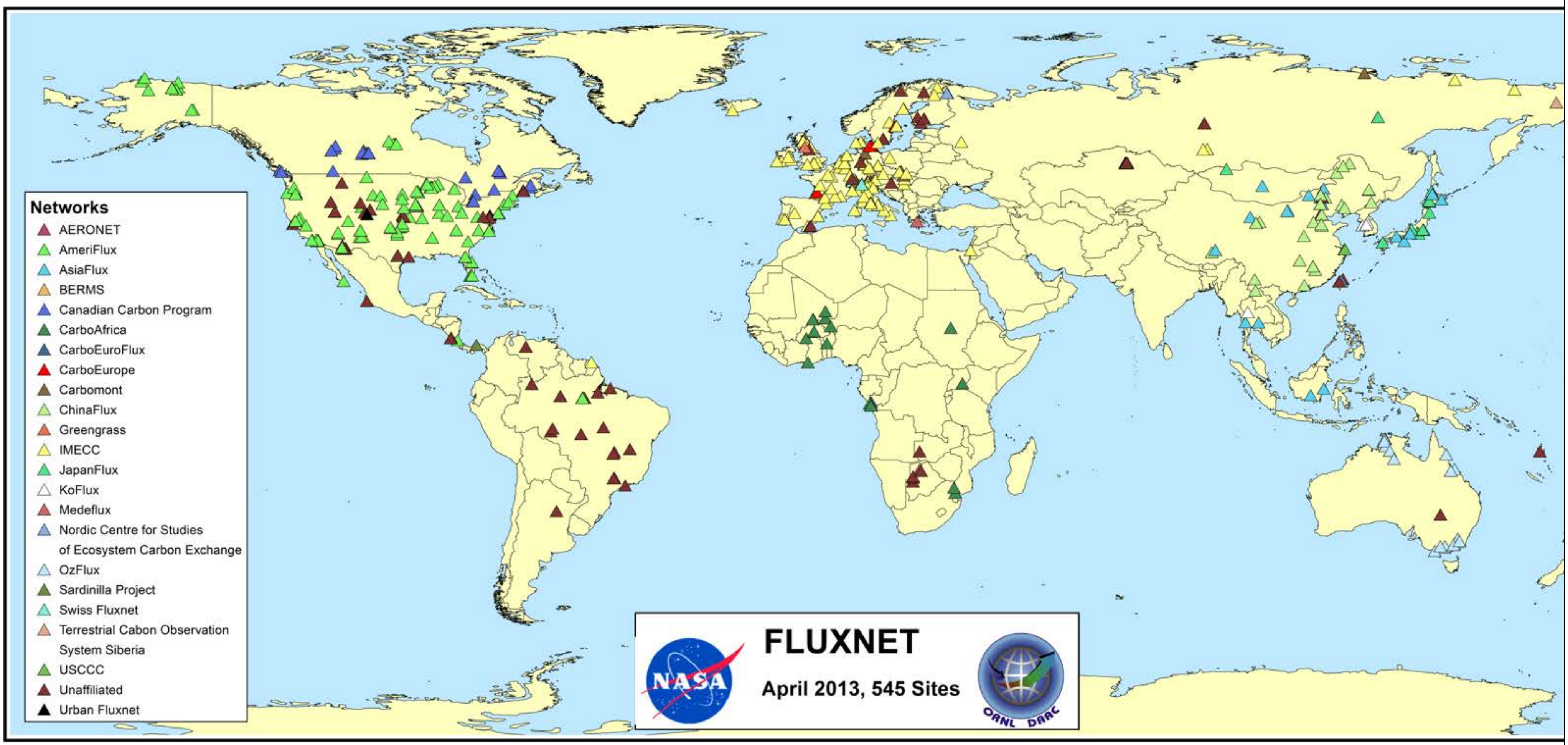
- Turbulent fluxes over the oceans are almost entirely unmonitored by in situ sensors

Locations of Validation Data; Buoys(Red) and R/V(Blue)



In-situ measured fluxes: not enough

- Similarly for land



Turbulent fluxes

- Fluxes are defined by:

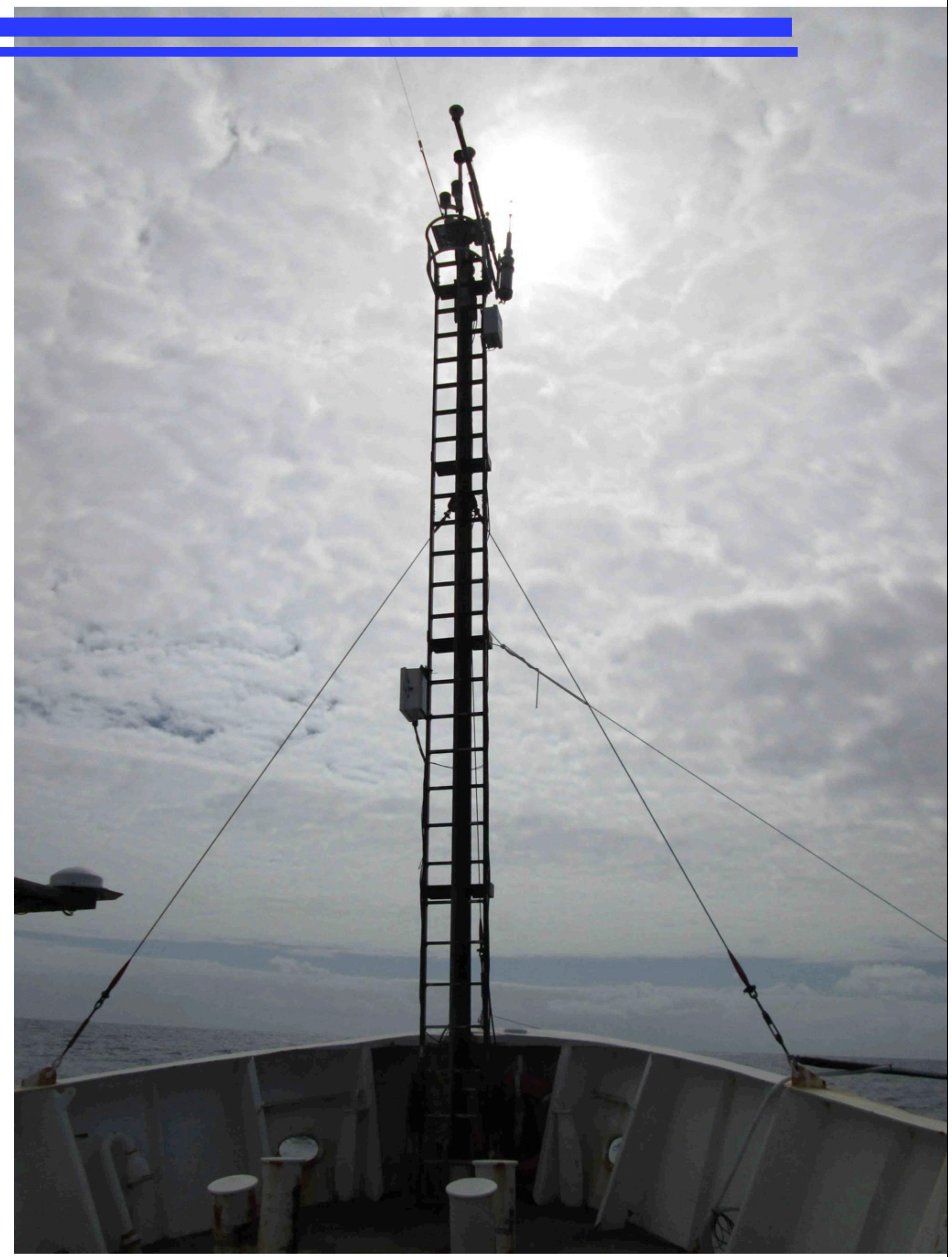
$$Q_H = \rho C_p \overline{w'\theta'}$$

$$Q_{LE} = \rho L_v \overline{w'q'}$$

- w': turbulent fluctuations of upward wind velocity
- q': turbulent fluctuations of humidity
- θ': turbulent fluctuations of temperature

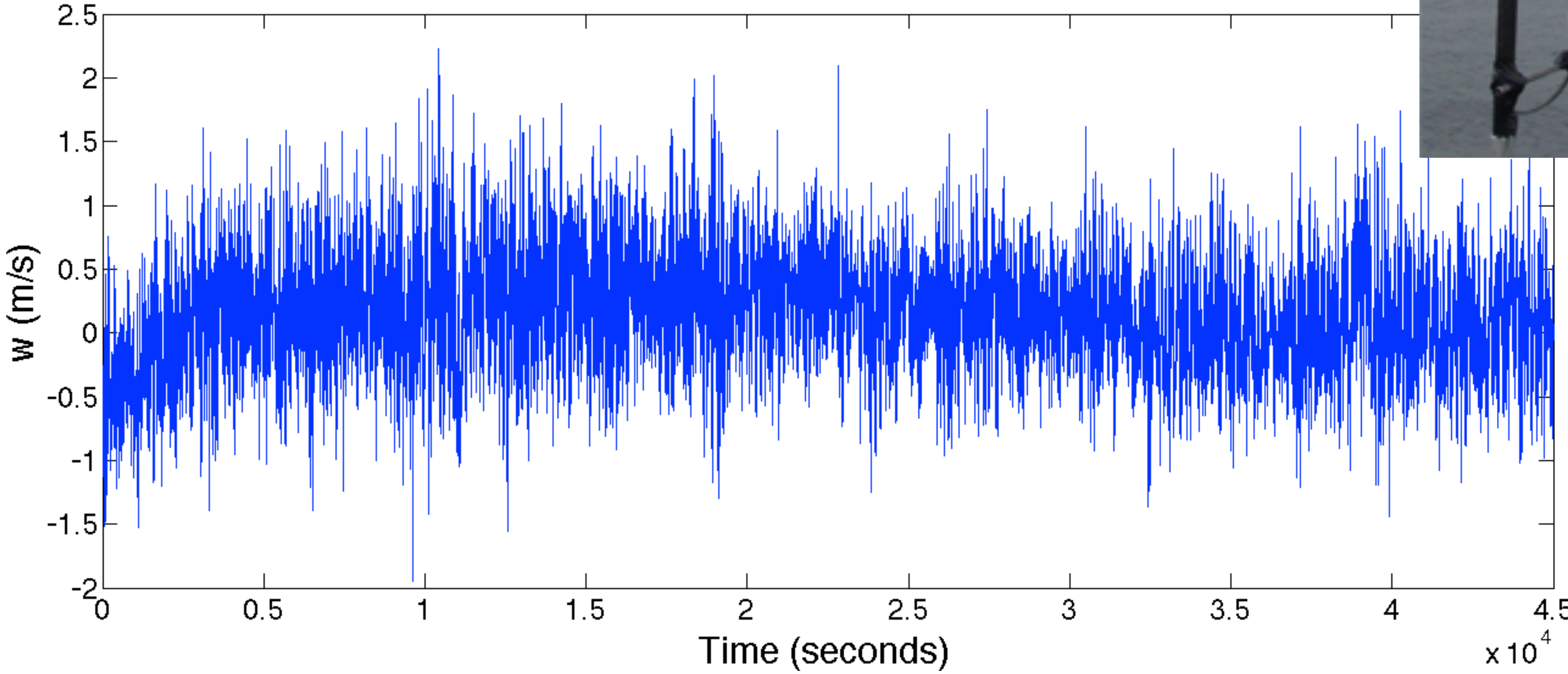
Go out and measure . . .

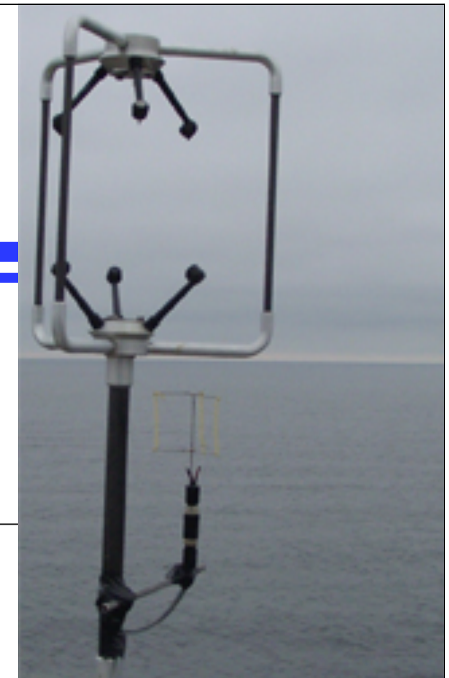
- Need: fast response instrument
- For winds: a sonic anemometer



Go out and measure . . .

- Sonic anemometer recording at 25 Hz

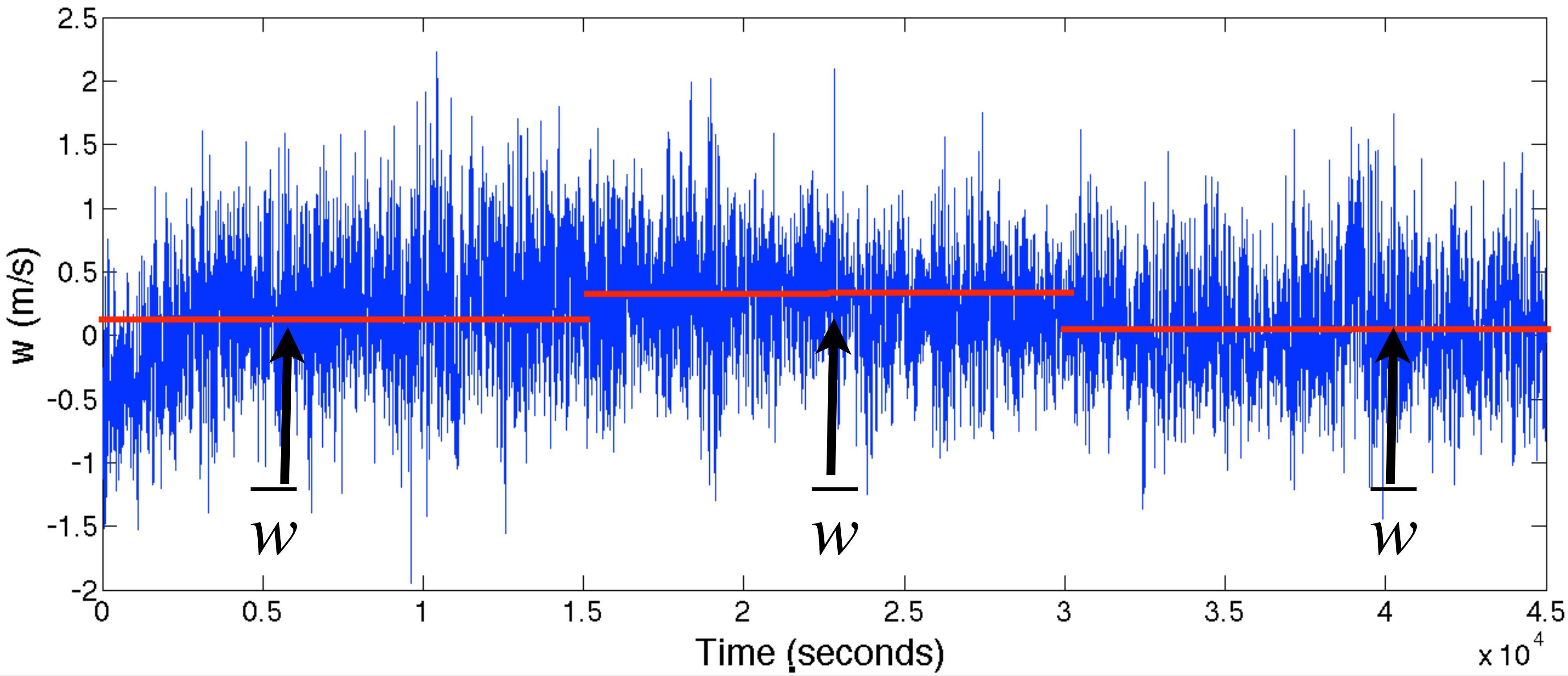




← 30 minutes →

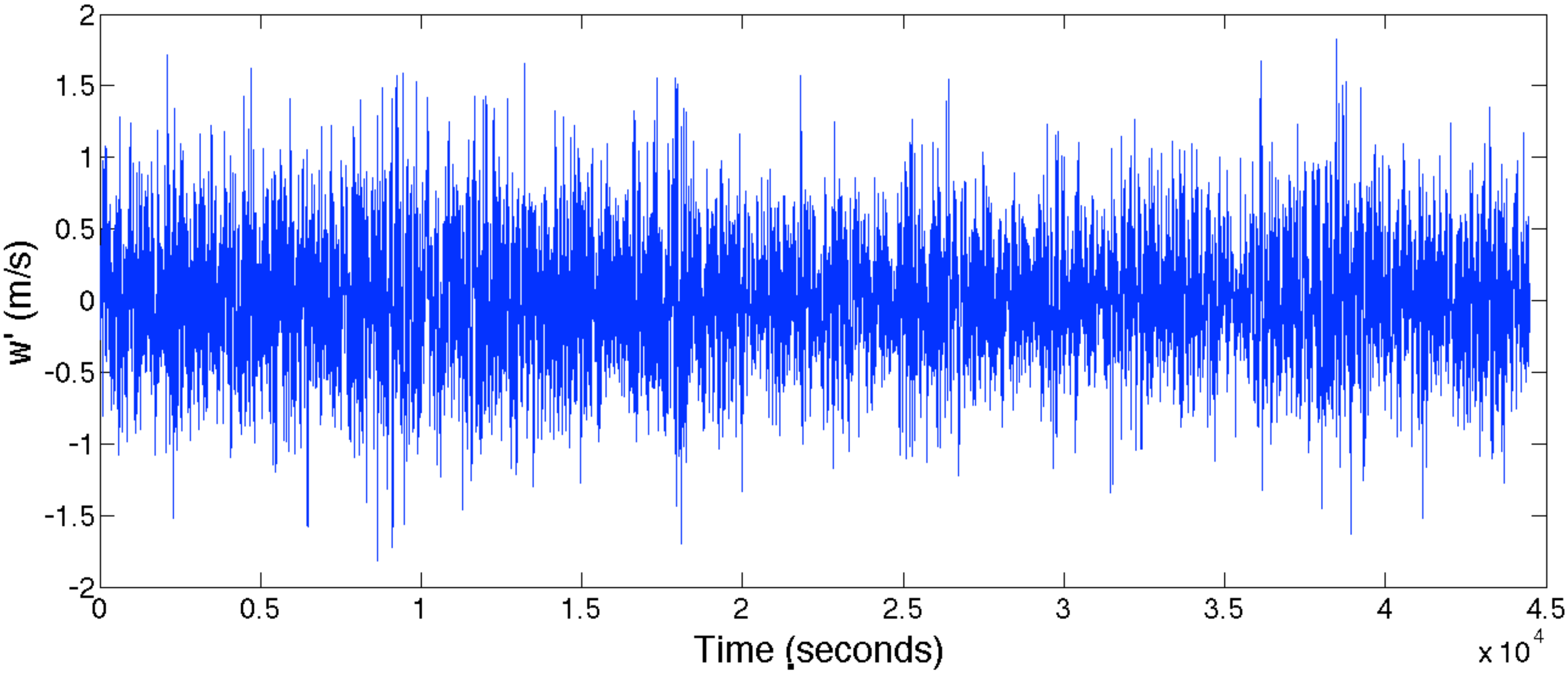
Go out and measure . . .

- Sonic anemometer recording at 25 Hz

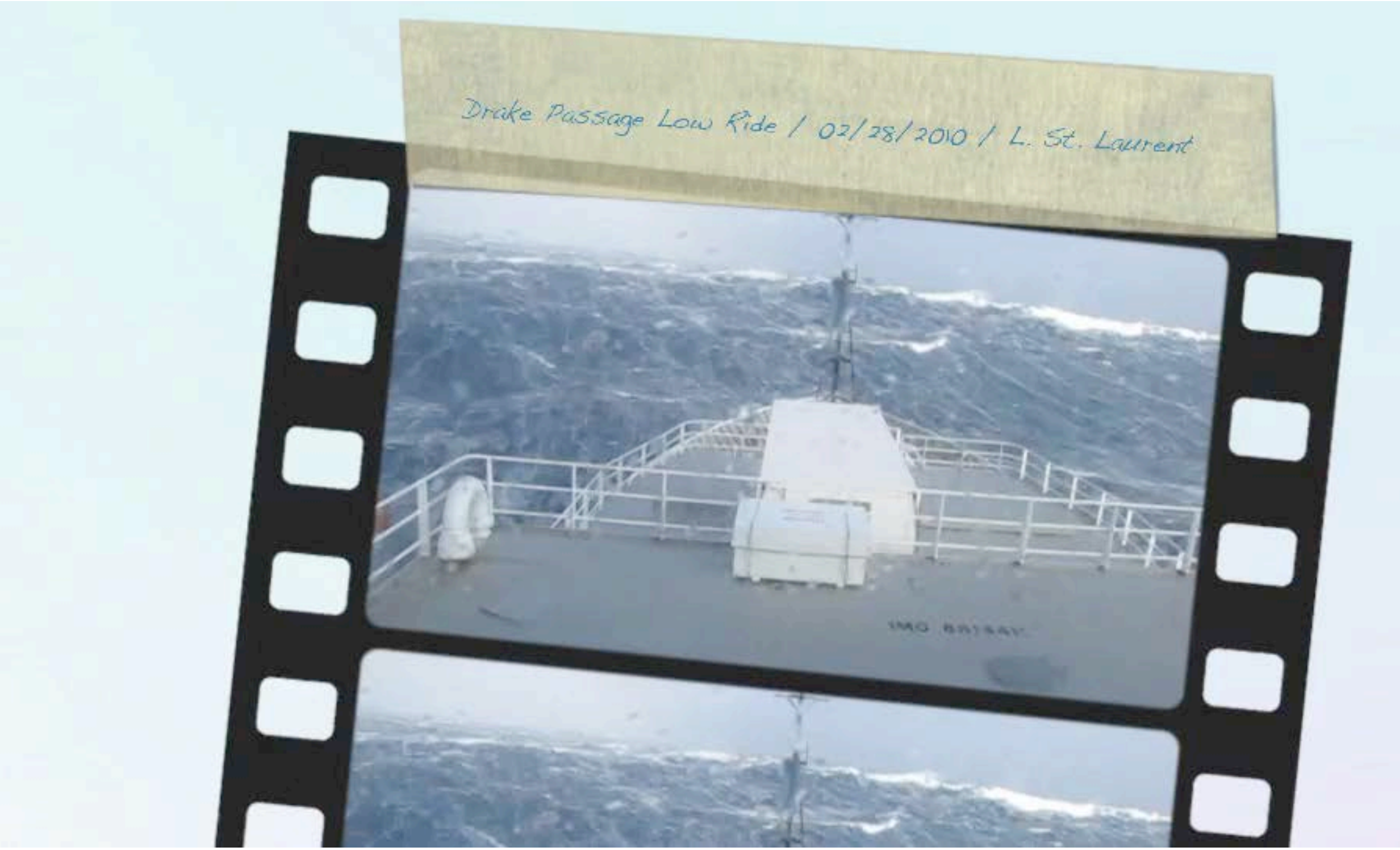


Go out and measure . . .

$$w' = w - \overline{w}$$



Why we don't do this often



On the land side

- Surface not moving
- But: turbulence not stationary; largest eddies may be affected by varying surface characteristics

- What this means: for ocean turbulence fluxes, eddy covariance measurements are “gold standard”. This is not true for land turbulence fluxes. Also: how to upscale for comparisons?

Estimating the ocean fluxes

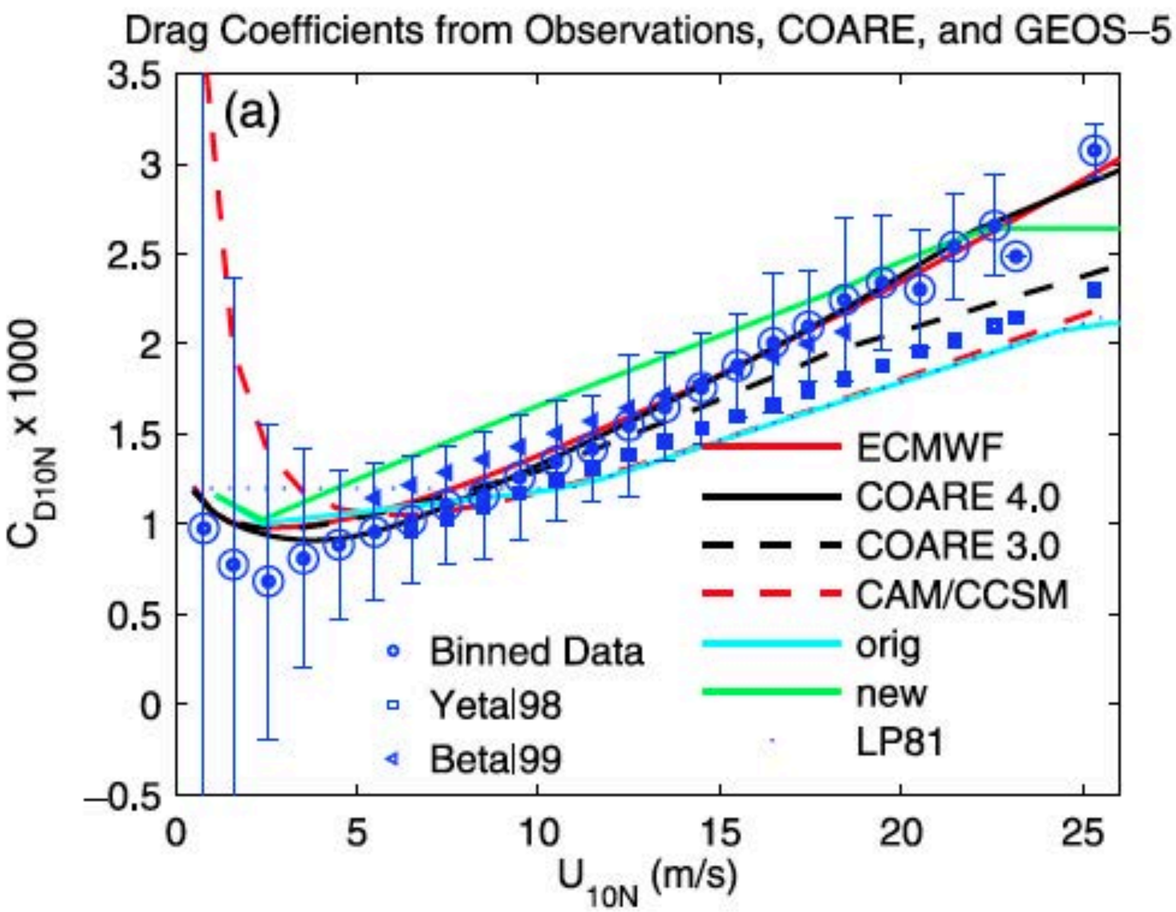
- From satellite we estimate the fluxes from the bulk equations:

$$Q_{LE} = \rho L_v \overline{w'q'} = \rho L_v (U_a - U_s) C_E (q_a - q_s)$$
$$Q_H = \rho C_p \overline{w'\theta'} = \rho C_p (U_a - U_s) C_H (T_a - T_s)$$

- Subscripts a and s denote values pertaining to the atmosphere at height z_h and at surface
- $C_{E,}$ C_H: bulk transfer coefficients: coefficients of water vapor or heat exchange (also called Dalton or Stanton number)
- Thus to calculate evaporation correctly we need: U_a, U_s, q_s, q_a T_s, T_a and an appropriate model of C_E and C_H

“Transfer coefficient”

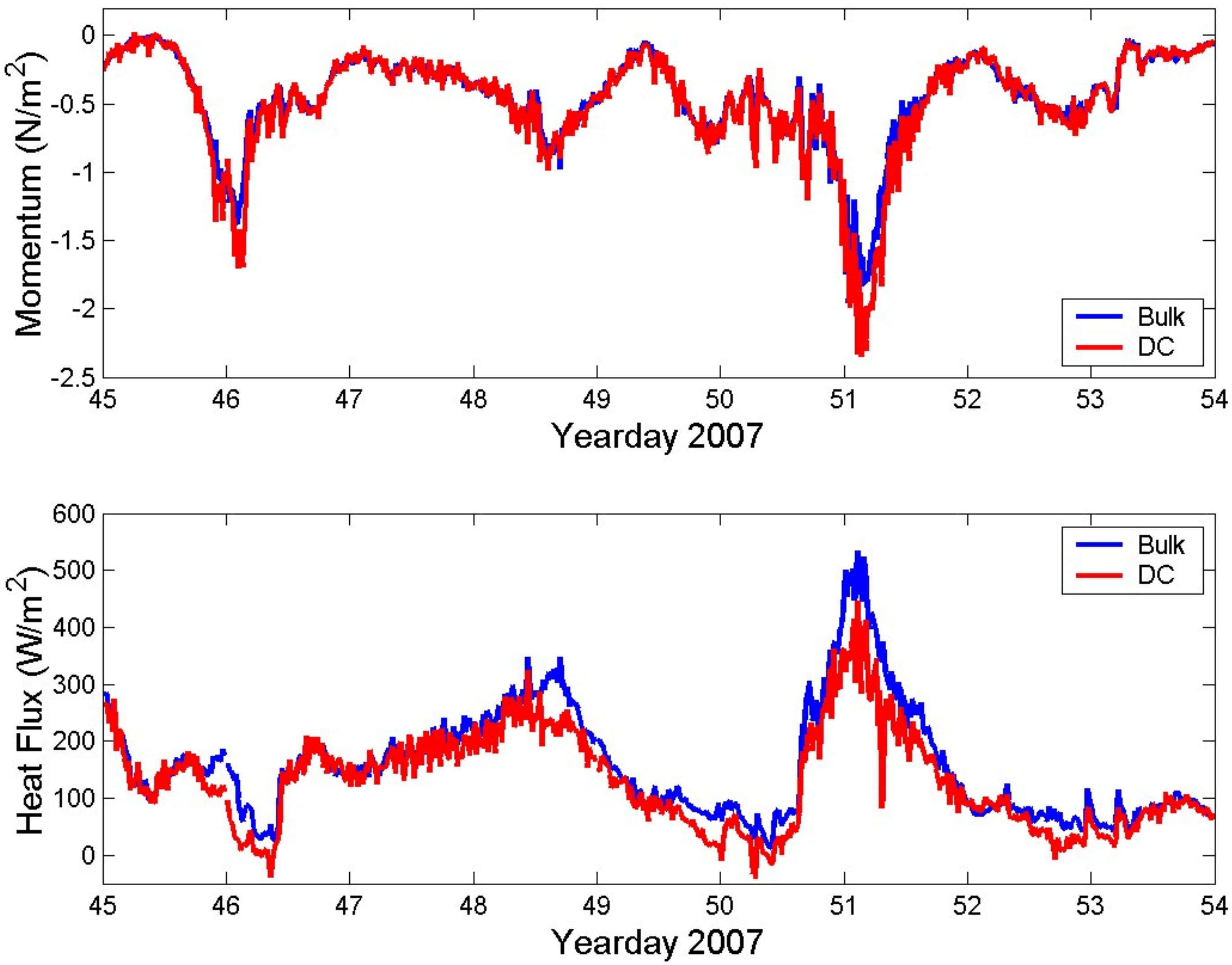
- Depends on:
  - Wave breaking
  - Roughness of sea surface
  - Air-sea temperature difference
  - Sea spray
  - ?



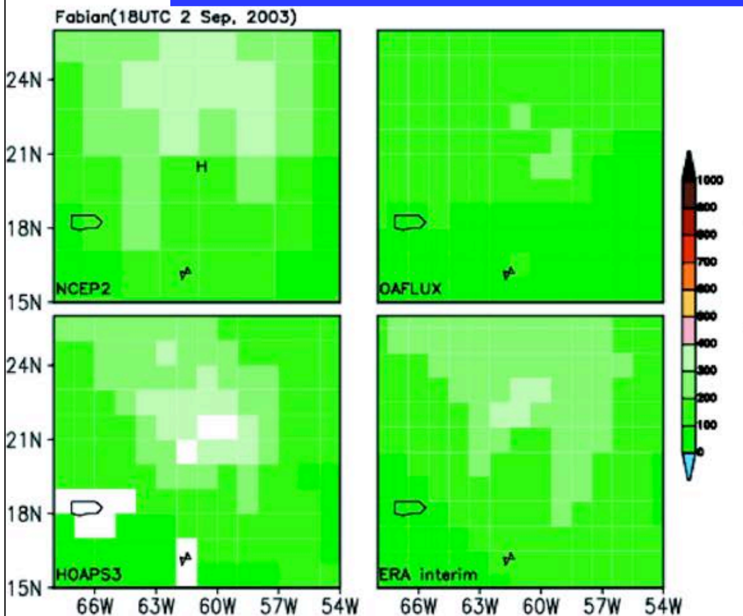
Garfinkel et al. 2011

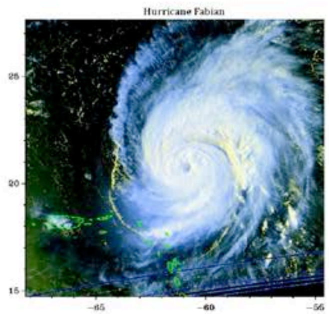
Estimating the fluxes

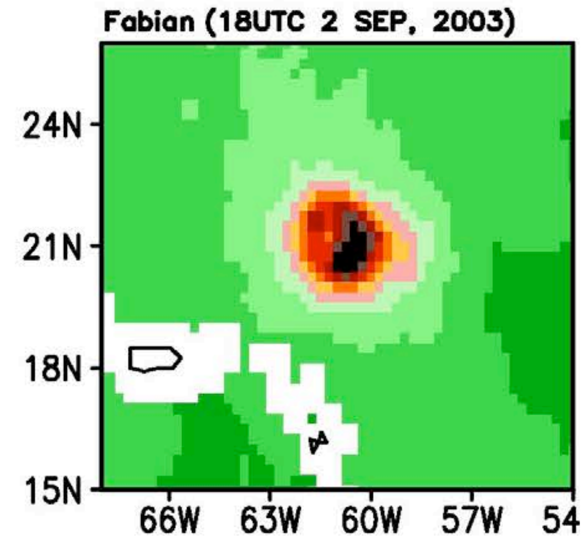
- How well we estimate is now both a function of how well we MEASURE and how good our MODEL is



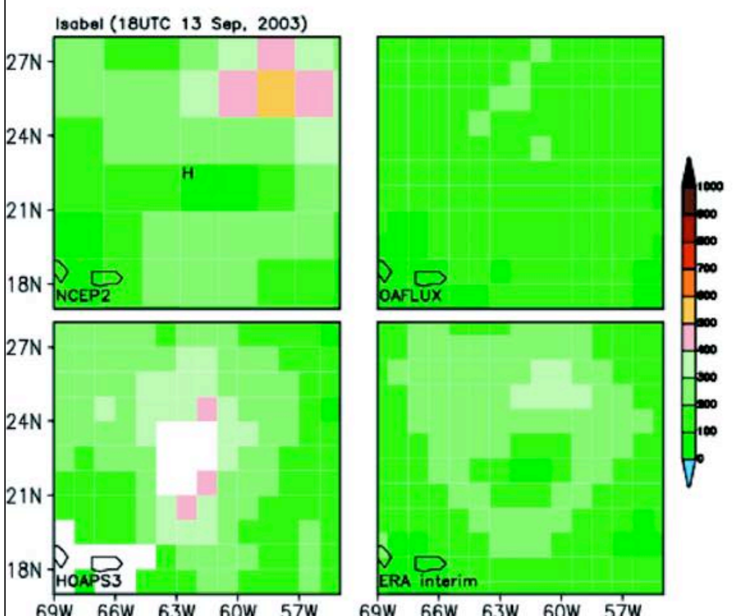
Hurricanes

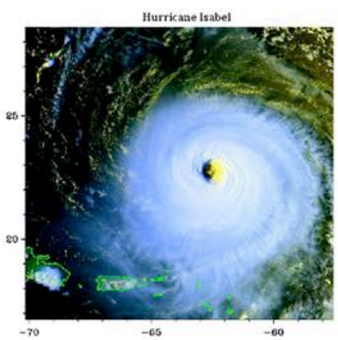


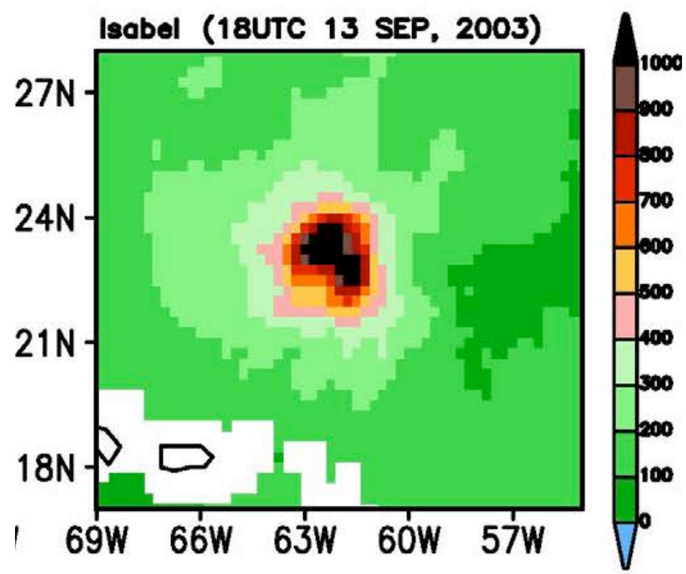




SeaFlux

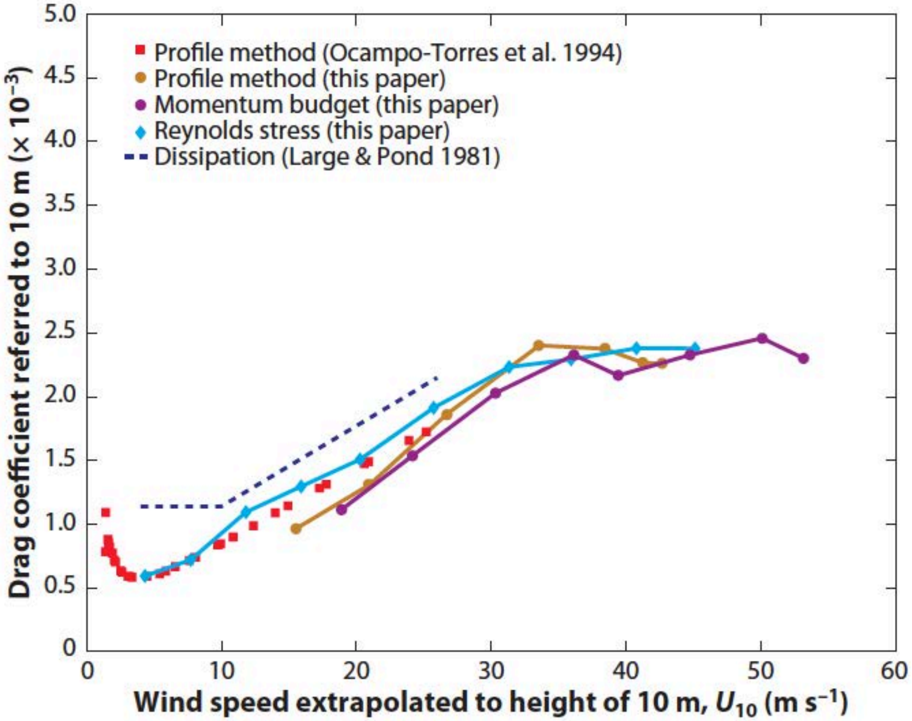




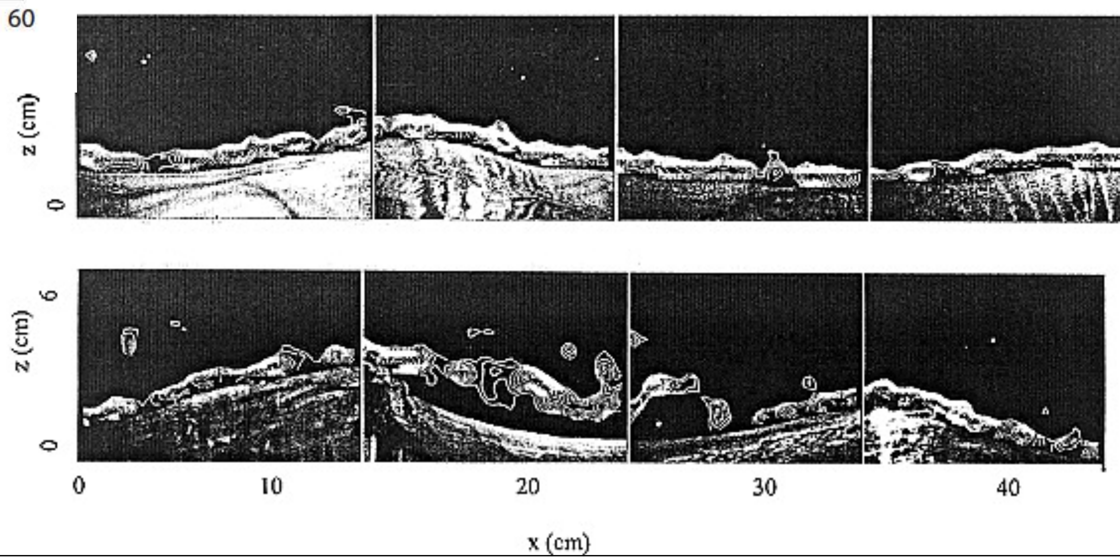


Liu et al. 2011

“Transfer coefficient”



- Plateau of C_D at wind speeds above 30 m/s in both laboratory and field measurements
  - Spray generation?
  - Flattening of wave crests accompanied by flow separation?

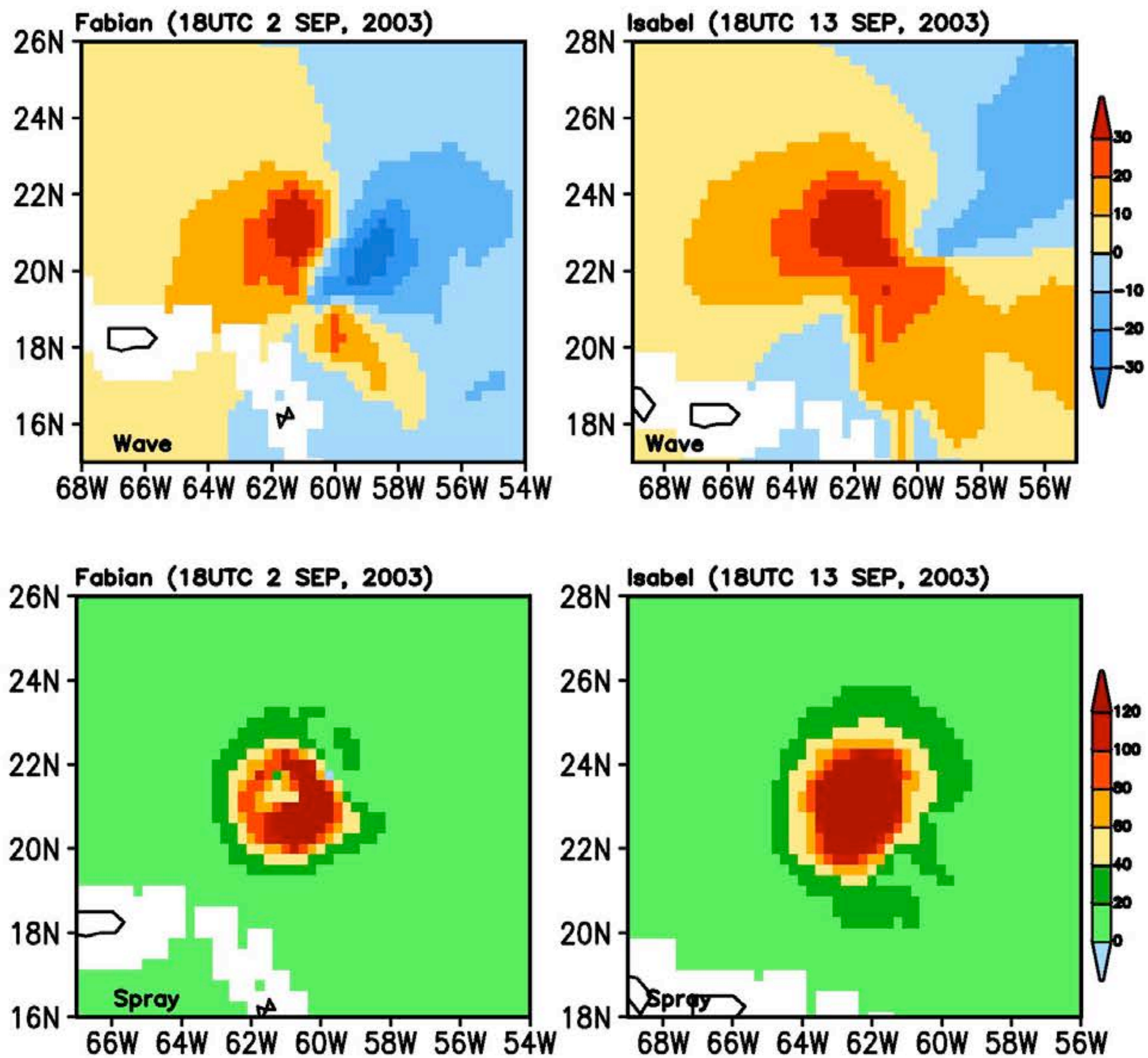


Sullivan and McWilliams 2010

Flux parameterization effects

Wave effects

Sea spray effects



5%

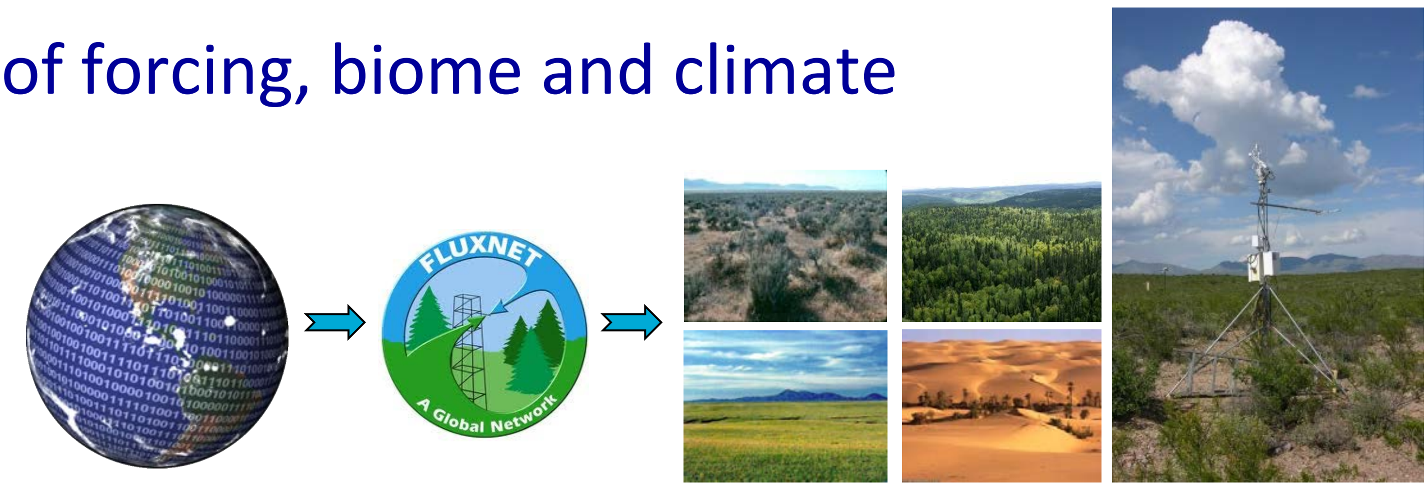
15%

Liu et al. 2011

Additional land concerns

Developing a long-term record of global heat fluxes

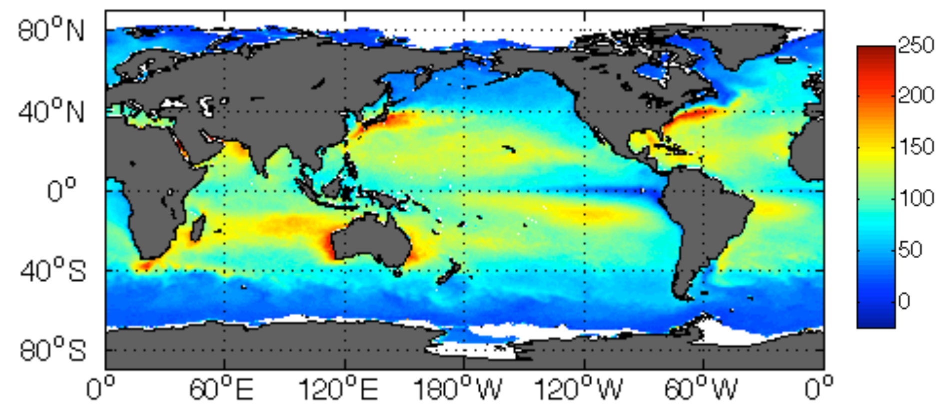
- Previously examined the global scale (space and time)
- Have studied the regional scale (Princeton + UNSW)
- Need to evaluate tower scale (forcing and fluxes)
    - Run models using common forcing data
    - Examine variability of model response
    - Impact of forcing, biome and climate



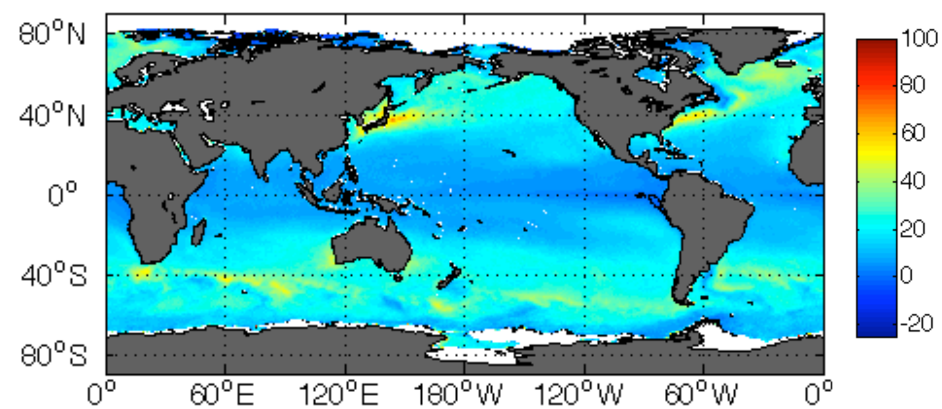
SeaFlux Climatological Data Set Version 1.0

- Near-surface air temperature and humidity
  - Roberts et al. (2010) neural net technique
  - SSM/I only from CSU brightness temperatures (thus only covers 1997 - 2006)
  - Gap-filling methodology -- use of MERRA variability – 3 hour
- Winds
  - Uses CCMP winds (cross-calibrated SSM/I, AMSR-E, TMI, QuikSCAT, SeaWinds)
  - Gap-filling methodology -- use of MERRA variability – 3 hour
- SST
  - Pre-dawn based on Reynolds OISST
  - Diurnal curve from new parameterization
  - Needs peak solar, precip
- Uses neural net version of COARE
- Available at http://seaflux.org

1999 Latent Heat Flux



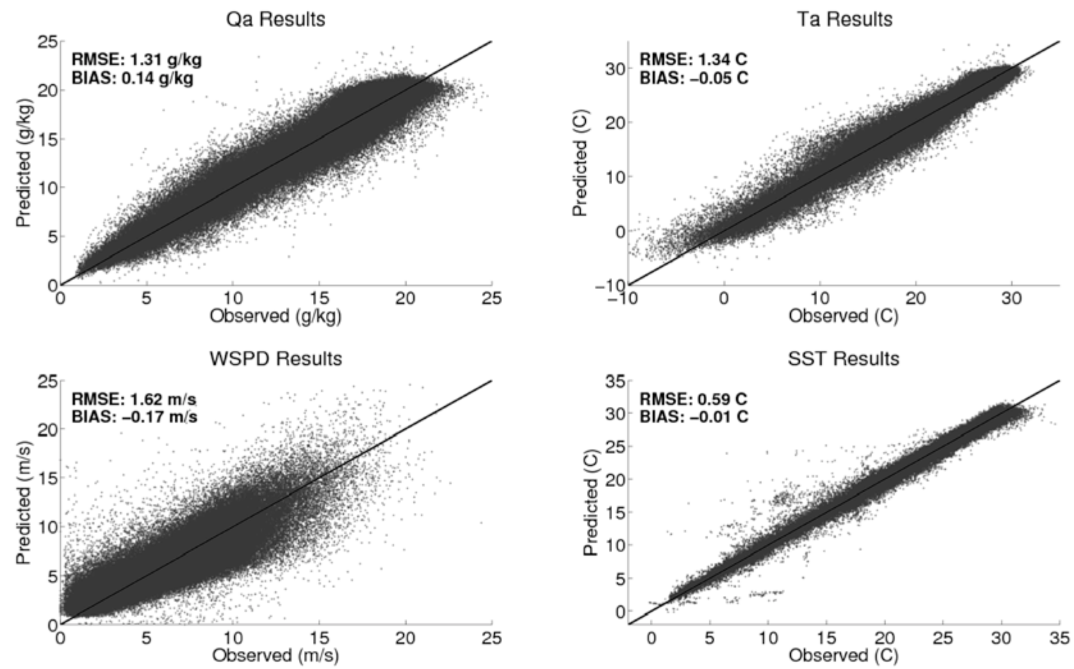
1999 Sensible Heat Flux

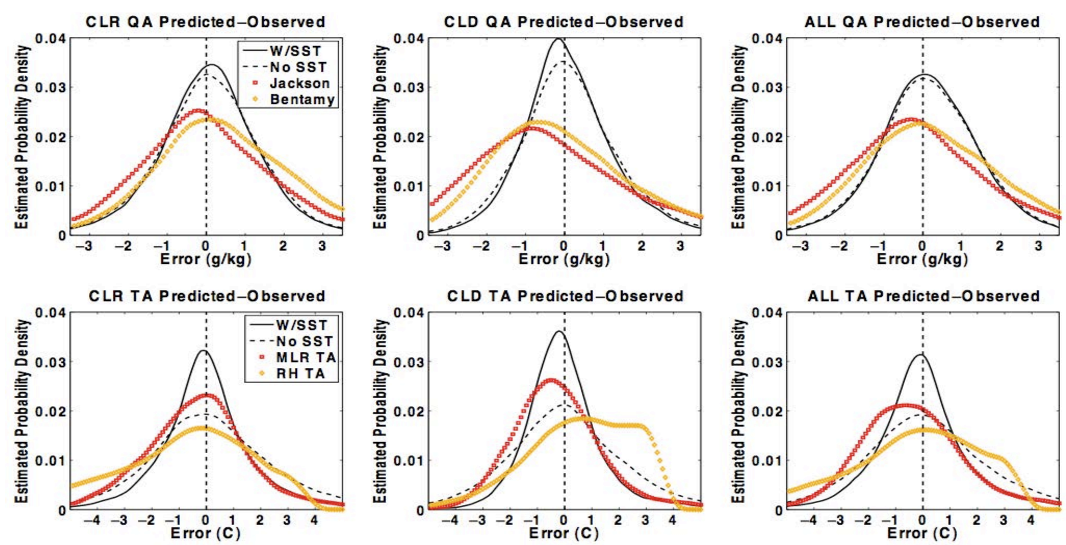


SEAFLUX

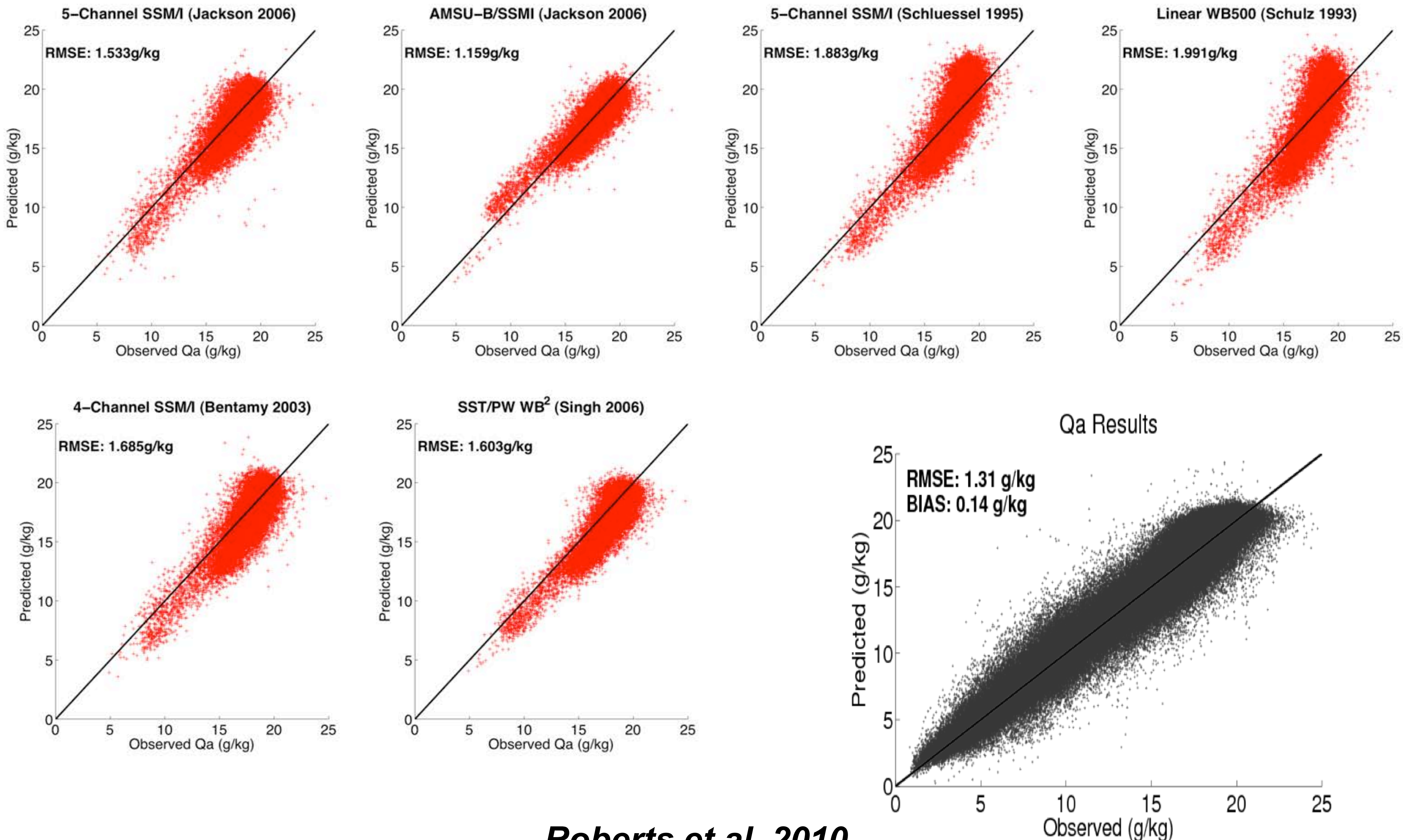
Ta, qa

- Use of neural net technique from SSM/I fields (Roberts et al. 2010)
- Gridding into equal-angle grids
- Interpolation using model gradients



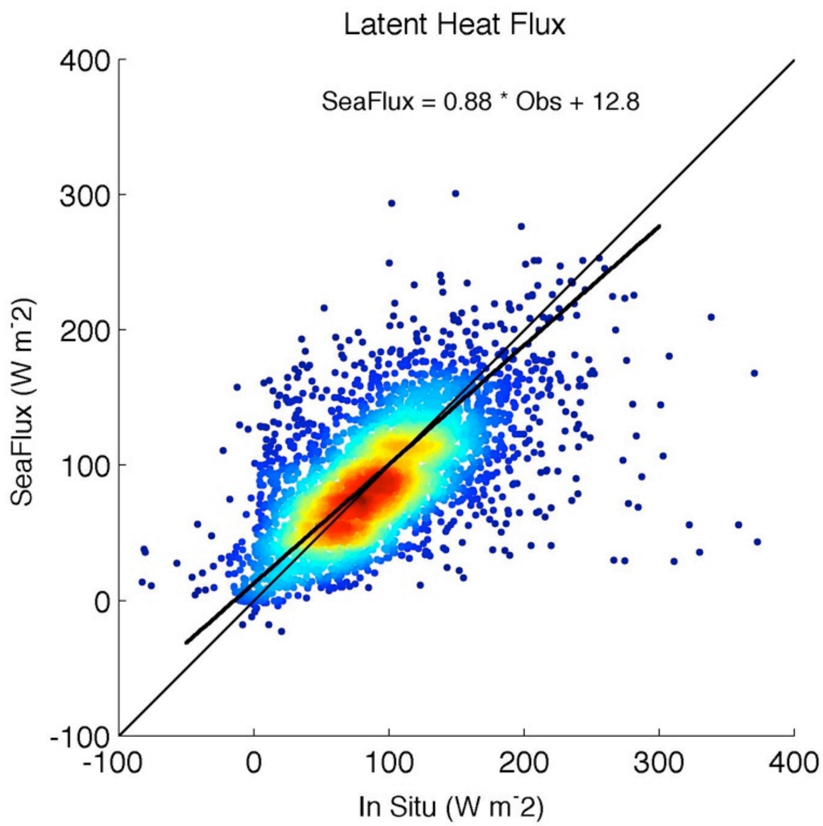


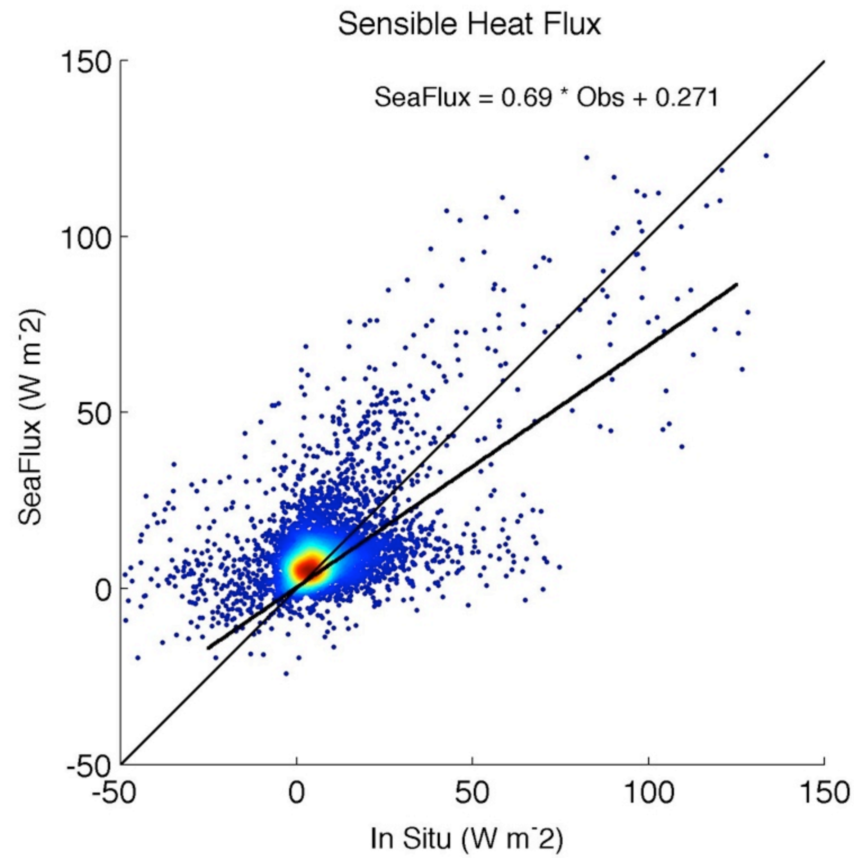
Retrievals of q_a



Roberts et al. 2010

Some comparisons





Bias: 2.1 W m^{-2}
Std Error: 38 W m^{-2}

Bias: -3.1 W m^{-2}
Std Error: 13.2 W m^{-2}

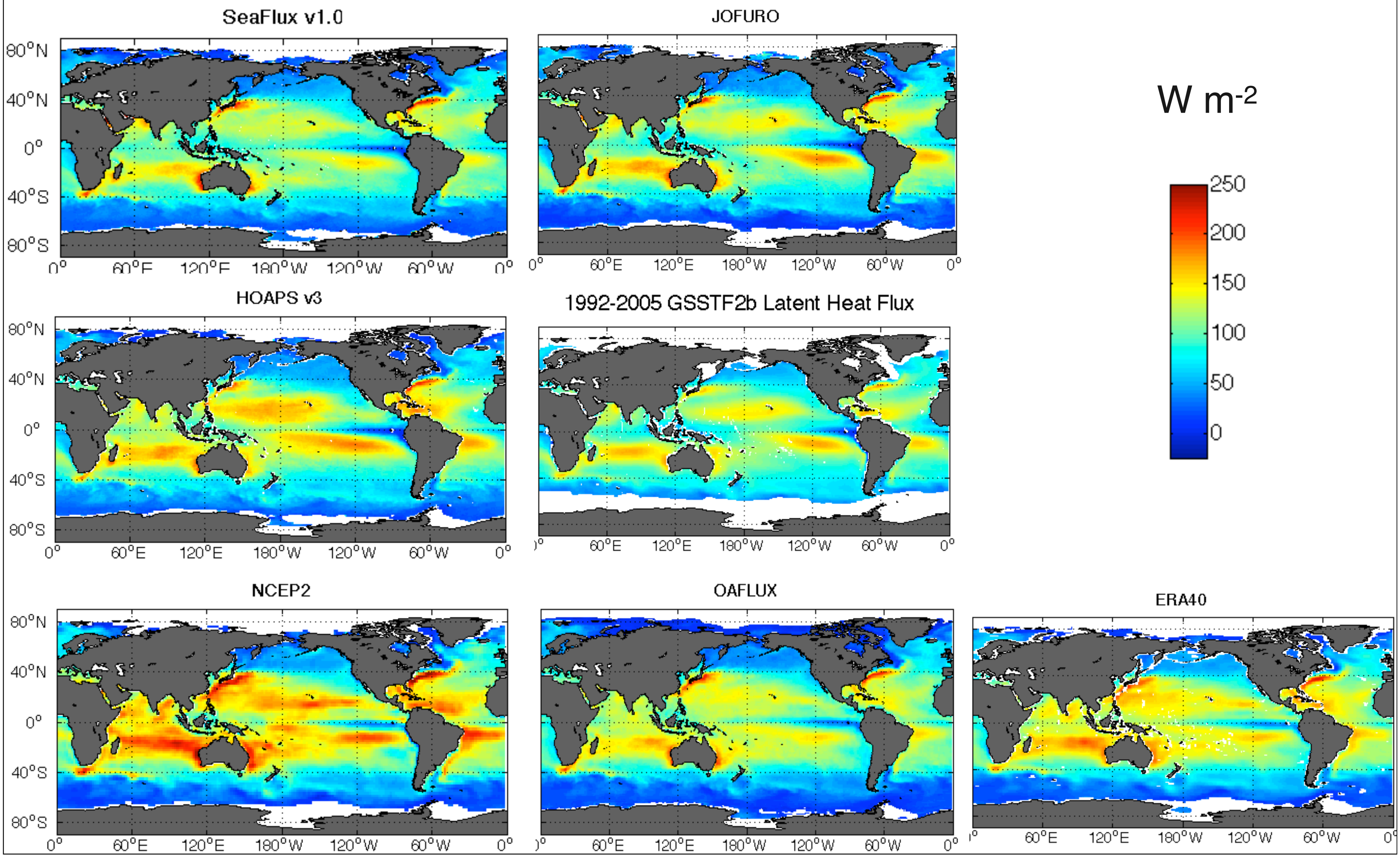
Here we do comparison with eddy covariance fluxes from research vessels -- they are our "ground truth"

Clayson et al. 2013

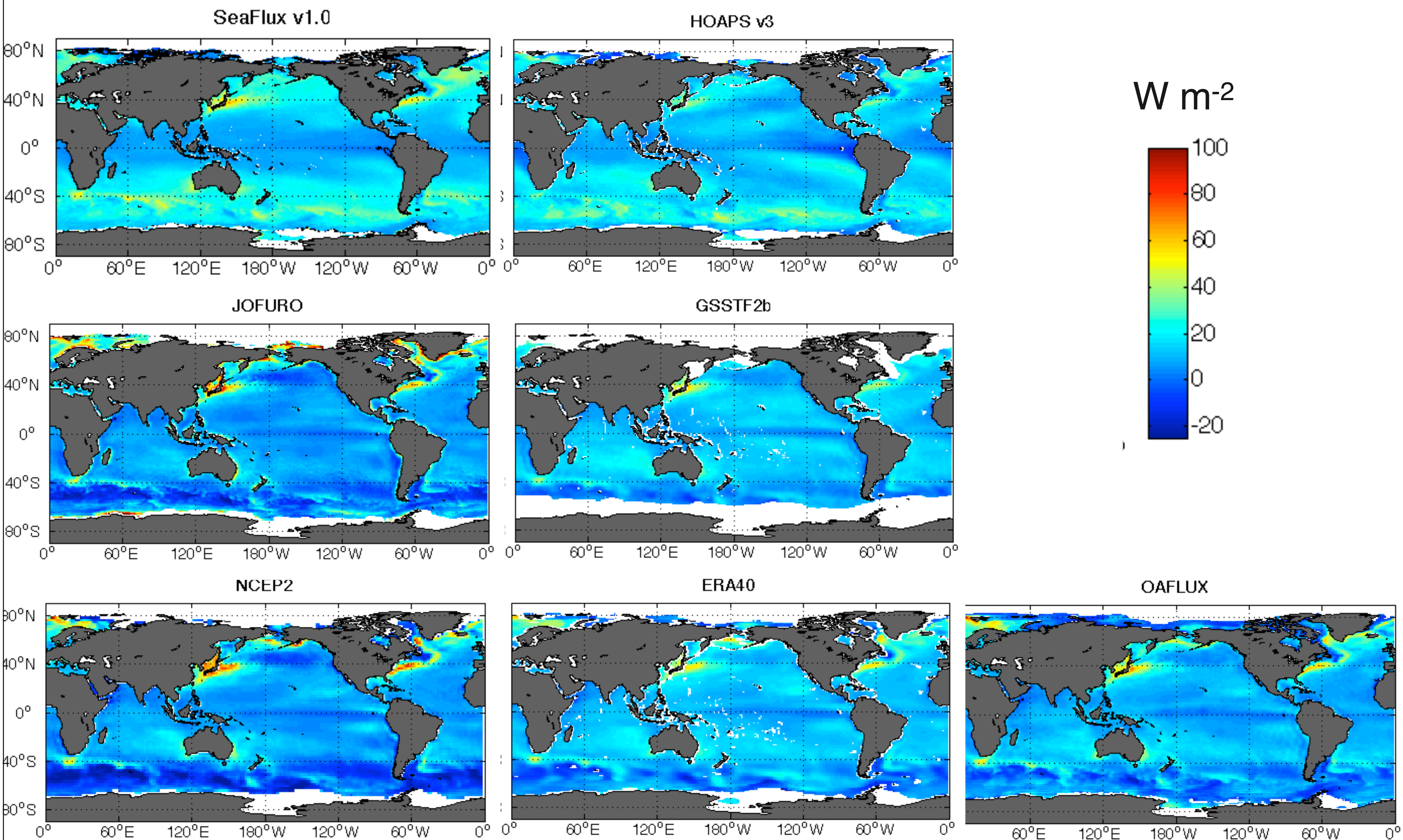
Climatological Datasets

- Goddard product: GSSTF/2b
  - Daily, 1°, input variables and turbulent fluxes
  - July 1987 - December 2007; global oceans
- IFREMER product
  - Weekly, 0.25°, input variables, turbulent fluxes
  - Currently available: 1992 – 2006; global oceans
- Japanese Ocean Flux datasets: J-OFURO2v2
  - Input variables, fluxes, radiation
    - Daily, 1°, 1988 – 2005; global oceans
    - Satellites, JMA model analyses
- HOAPS3
  - Twice-daily, 0.5°, 1987 - 2005, global oceans
  - July 1987 - December 2005

Latent Heat Flux: 1999-2005



Sensible Heat Flux: 1999 - 2005



On the land side

- Can not measure what is needed from satellite to calculate the fluxes with the bulk algorithms
- Satellite products use a neural net or other statistical technique or model and generally a combination of the following inputs:
  - Backscatter (ERS among others) -- provides information on soil and vegetation moisture, vegetation coverage, and surface roughness
  - AVHRR visible and infrared reflectances (vegetation information)
  - SSM/I emissivities at 19v and 19h
  - skin temperature (ISCCP), it's diurnal cycle (also ISCCP)
  - net radiation (often ISCCP)

On the land side

- **Satellite-based** products (process-based, empirical)

ELSEVIER Remote Sensing of Environment 112 (2008) 901–919 www.elsevier.com/locate/rse

Global estimates of the land–atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites

Joshua B. Fisher [a,*], Kevin P. Tu [b], Dennis D. Baldocchi [a]

JOURNAL OF HYDROMETEOROLOGY VOLUME 9

An Improved Method for Estimating Global Evapotranspiration Based on Satellite Determination of Surface Net Radiation, Vegetation Index, Temperature, and Soil Moisture

KAICUN WANG

Department of Geography, University of Maryland, College Park, College Park, Maryland, and Laboratory for Middle Atmosphere and Global Environment Observation, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

SHUNLIN LIANG

Department of Geography, University of Maryland, College Park, College Park, Maryland

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D06305, doi:10.1029/2

Toward an estimation of global land surface heat fluxes from multisatellite observations

Carlos Jiménez,[1] Catherine Prigent,[1] and Filipe Aires[2]

ELSEVIER Remote Sensing of Environment 111 (2007) 519–536 www.elsevier.com/locate/rse

Development of a global evapotranspiration algorithm based on MODIS and global meteorology data

Qiaozhen Mu *, Faith Ann Heinsch, Maosheng Zhao, Steven W. Running

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, G00J07, doi:1

Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations

Martin Jung,[1] Markus Reichstein,[1] Hank A. Margolis,[2] Alessandro Cescatti,[3] Andrew D. Richardson,[4] M. Altaf Arain,[5] Almut Arneth,[6,7] Christian Bernhofer,[8] Damien Bonal,[9] Jiquan Chen,[10] Damiano Gianelle,[11] Nadine Gobron,[12] Gerald Kiel Werner Kutsch,[14] Gitta Lasslop,[1] Beverly E. Law,[15] Anders Lindroth,[6] Lutz Merbol Leonardo Montagnani,[17,18] Eddy J. Moors,[19] Dario Papale,[20] Matteo Sottocornola,[1] Francesco Vaccari,[21] and Christopher Williams[22]

Hydrol. Earth Syst. Sci., 15, 453–469, 2011
www.hydrol-earth-syst-sci.net/15/453/2011/
doi:10.5194/hess-15-453-2011

Hydrology and Earth System Sciences

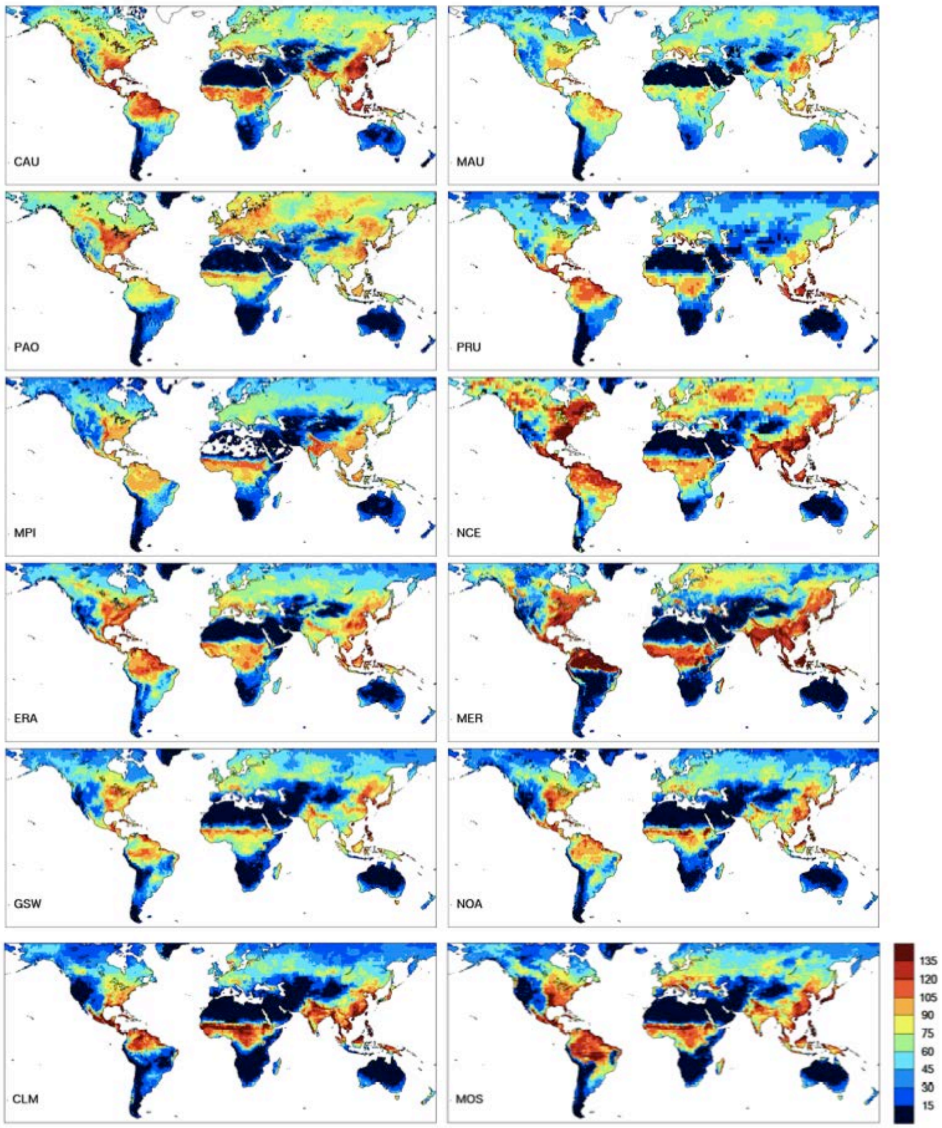
Global land-surface evaporation estimated from satellite-based observations

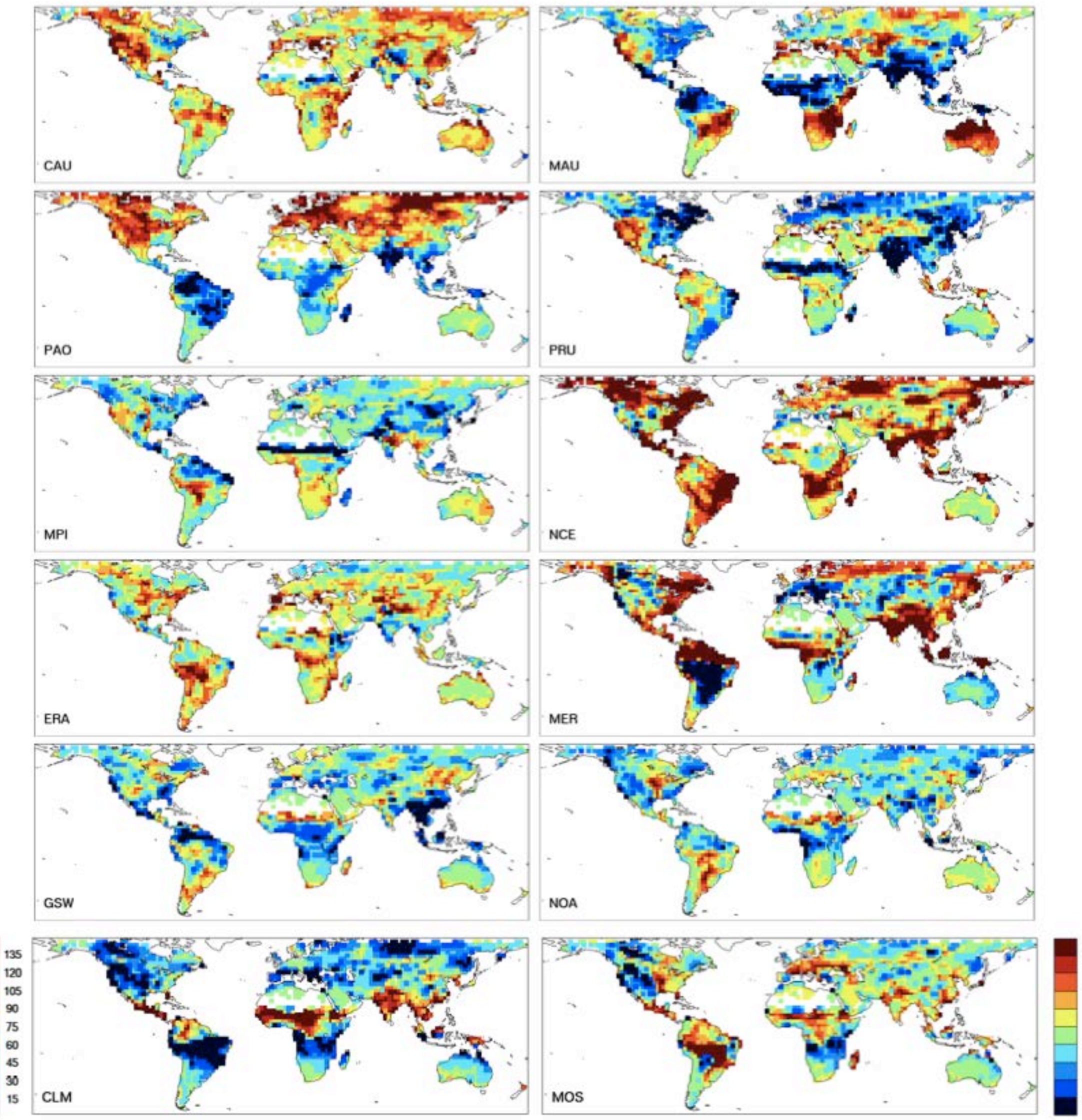
D. G. Miralles[1], T. R. H. Holmes[1,2], R. A. M. De Jeu[1], J. H. Gash[1], A. G. C. A. Meesters[1], and A. J. Dolman[1]

[1]Department of Hydrology, VU University, Amsterdam, The Netherlands
[2]Hydrology and Remote Sensing Lab, USDA-ARS, Beltsville, MD, USA

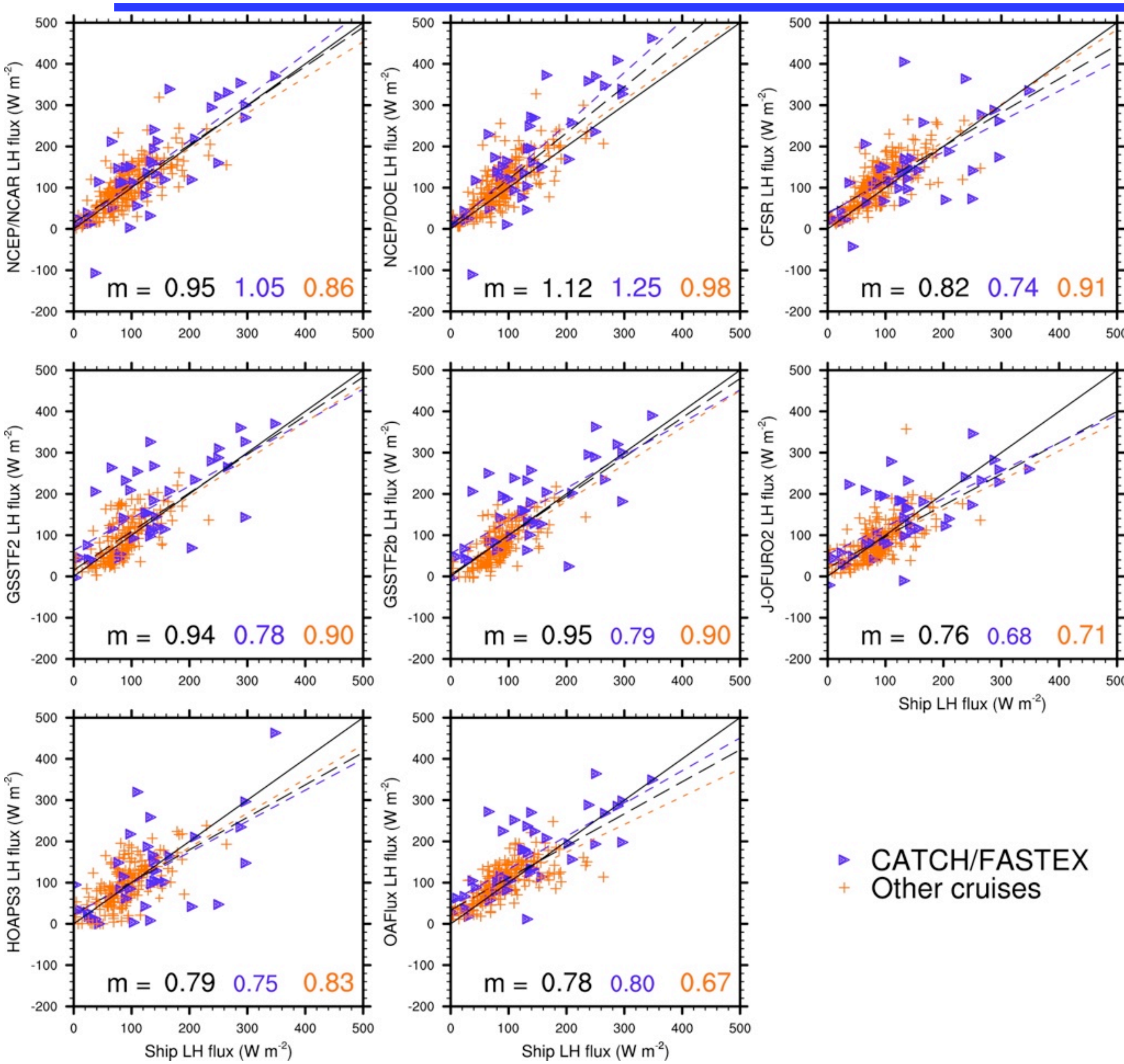
Received: 14 October 2010 – Published in Hydrol. Earth Syst. Sci. Discuss.: 27 October 2010
Revised: 15 January 2011 – Accepted: 26 January 2011 – Published: 3 February 2011

Latent Heat Flux





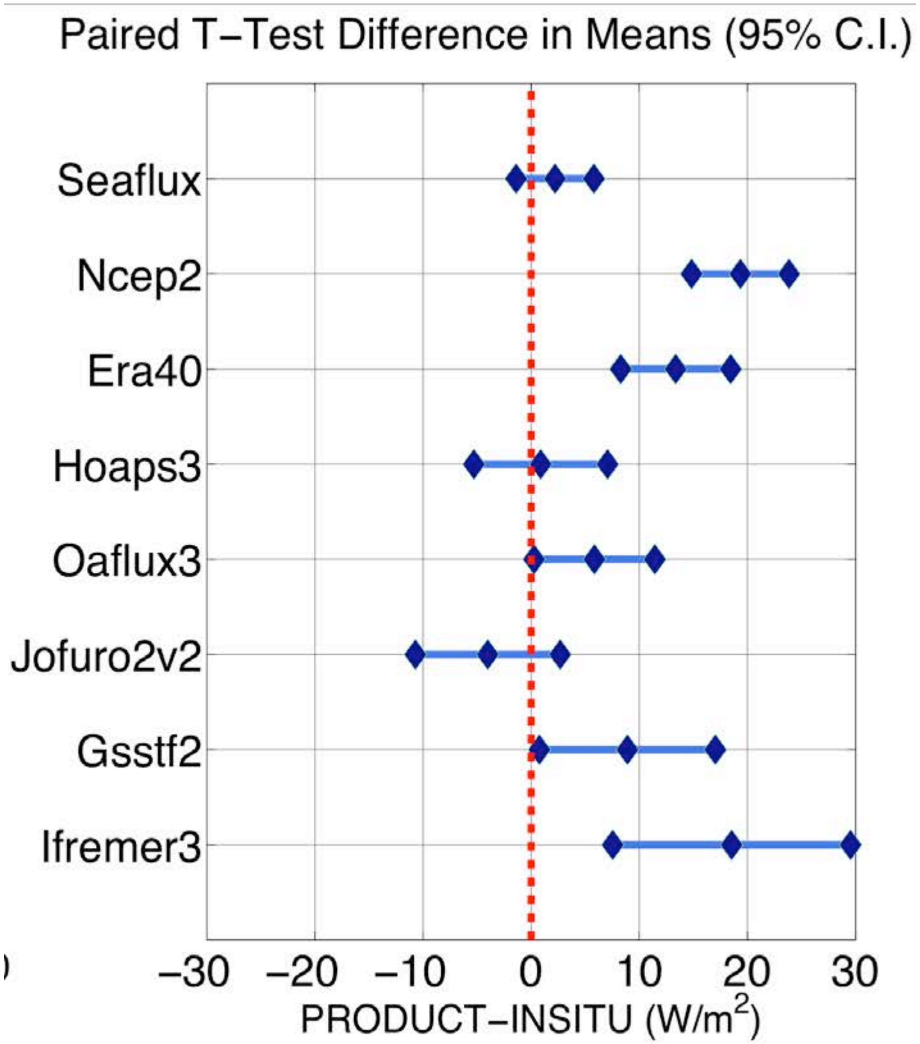
Some ocean comparisons

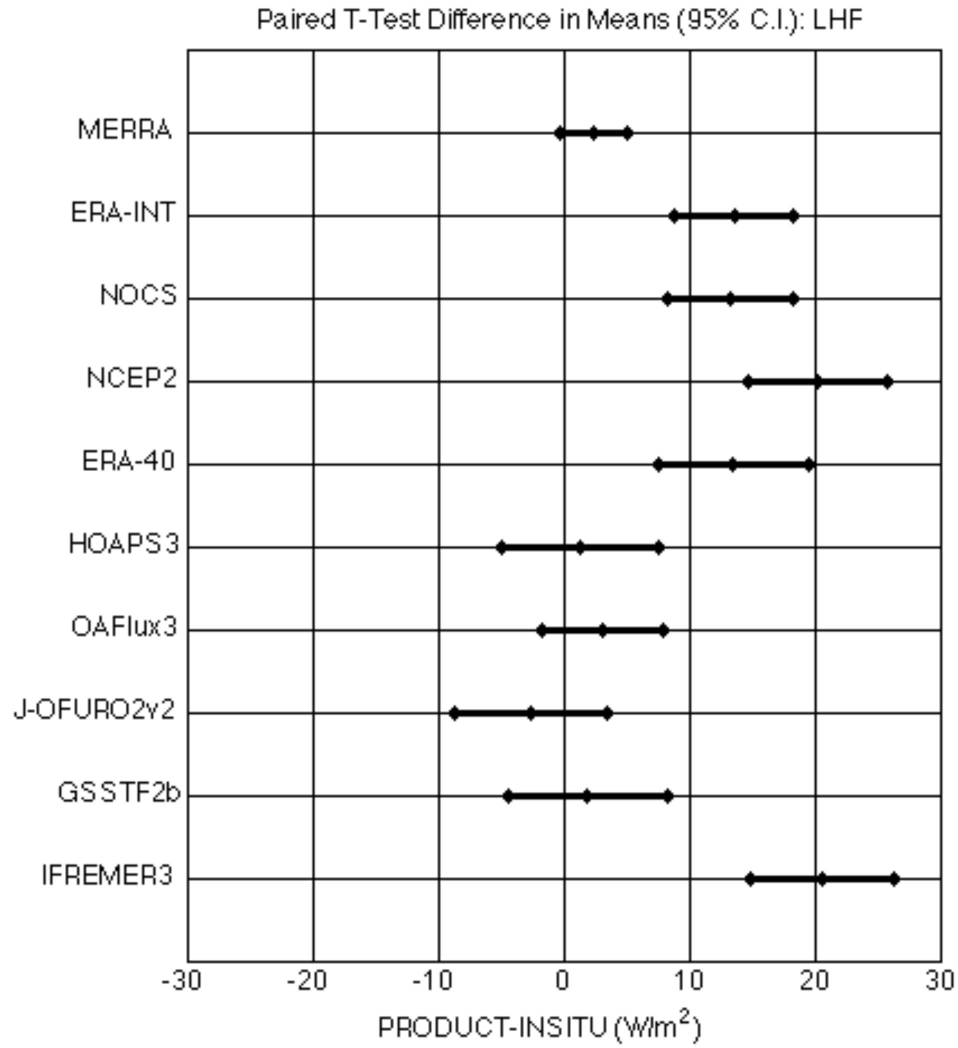


Group	LH flux	SH flux
A	ERA-40	GSSTF2b
	ERA-Interim	MERRA
	GSSTF2b	NCEP–DOE
	MERRA	OAFlux
B	CFSR	CFSR
	J-OFURO	ERA-40
	NCEP–NCAR	ERA-Interim
	OAFlux	HOAPS
C	HOAPS	GSSTF2
	GSSTF2	J-OFURO
	NCEP–DOE	NCEP–NCAR

Brunke et al. 2011

Some sample comparisons



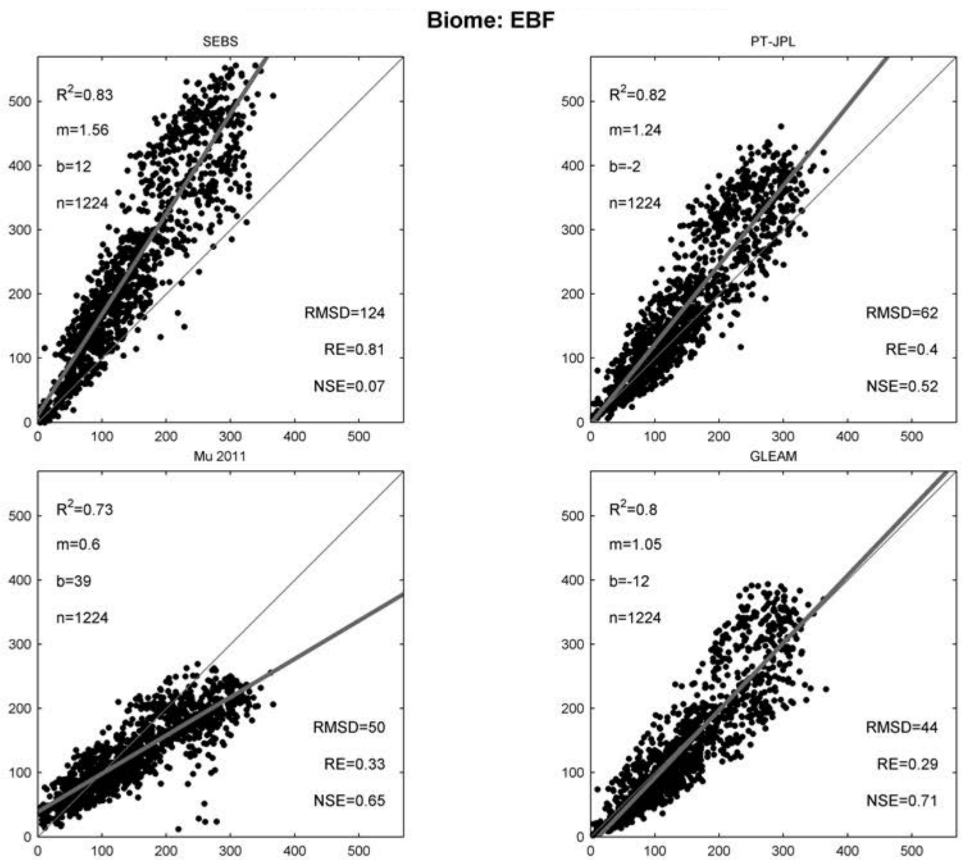


Some land comparisons (LHF)

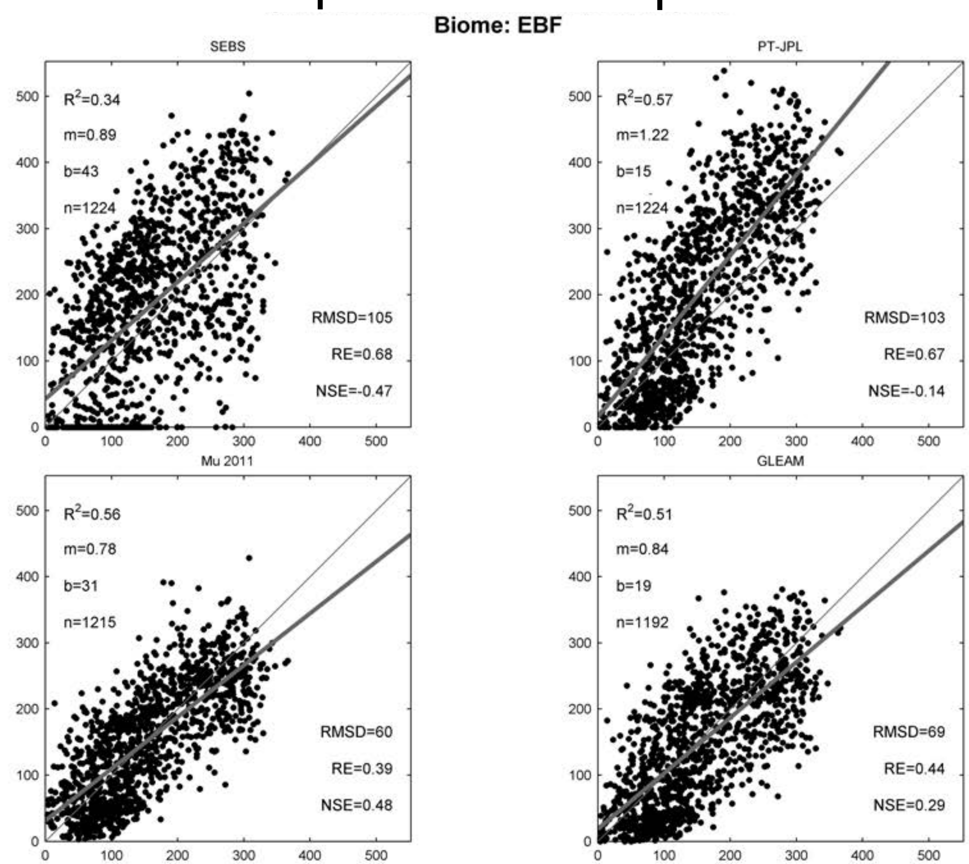
Variation via biome type at GRID and TOWER scales

- Filtered to 45 “common” towers to simulate ALL models

Flux Tower: 3hr



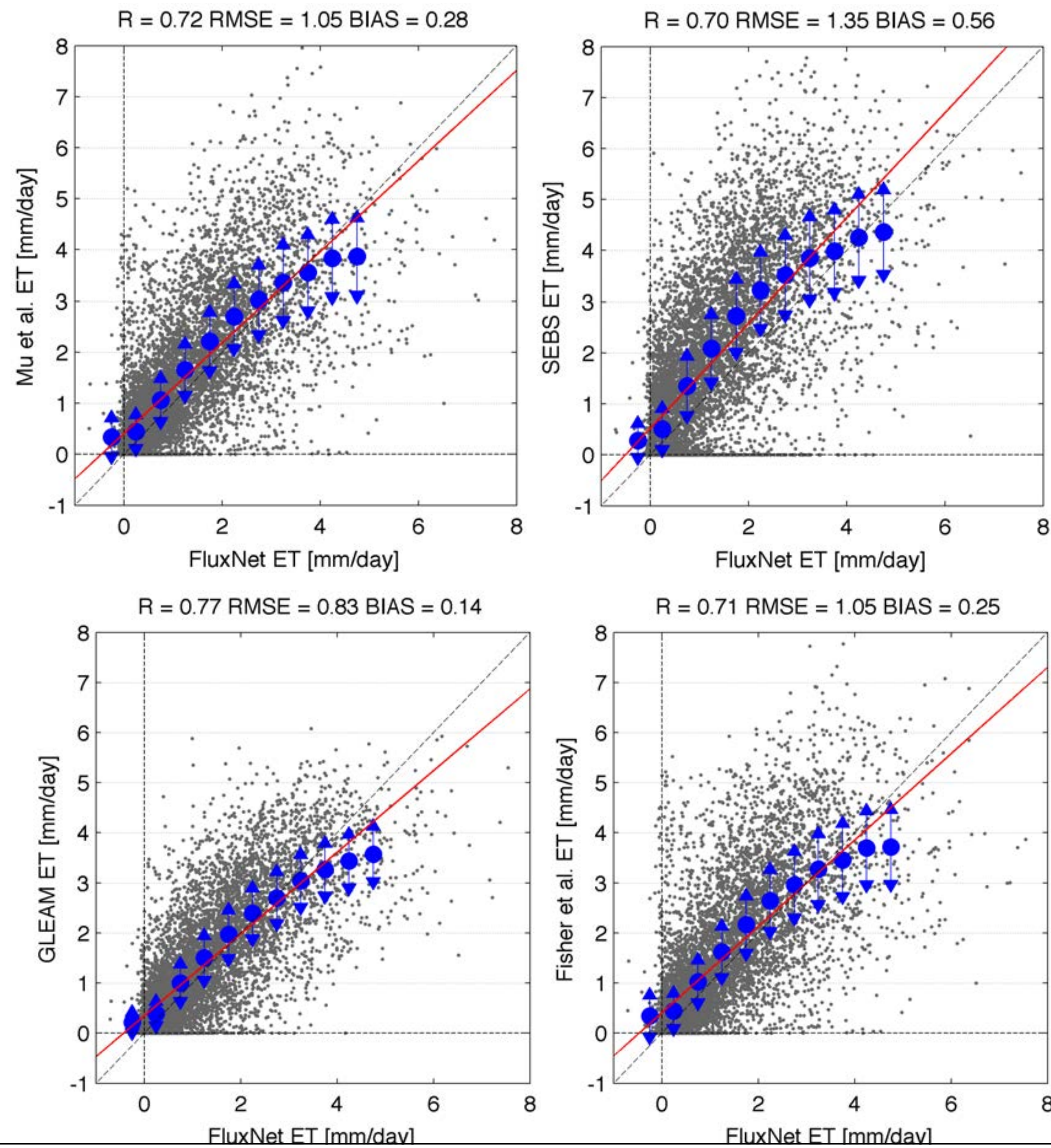
LandFLUX: 3hr



McCabe 2013

Some land comparisons (LHF)

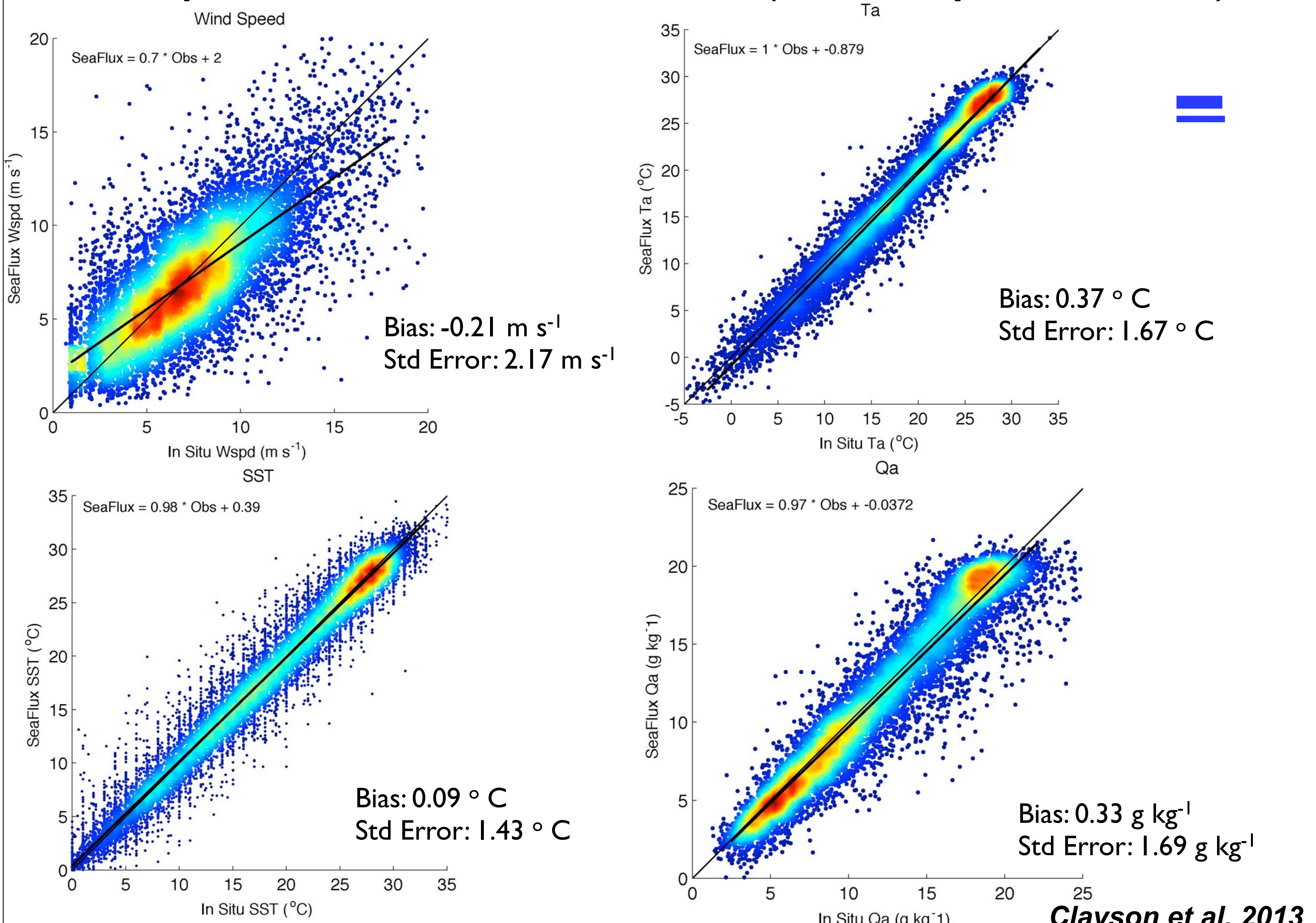
• Evaluation using **La Thuile FLUXNET** Synthesis Dataset



78.908 daily observations

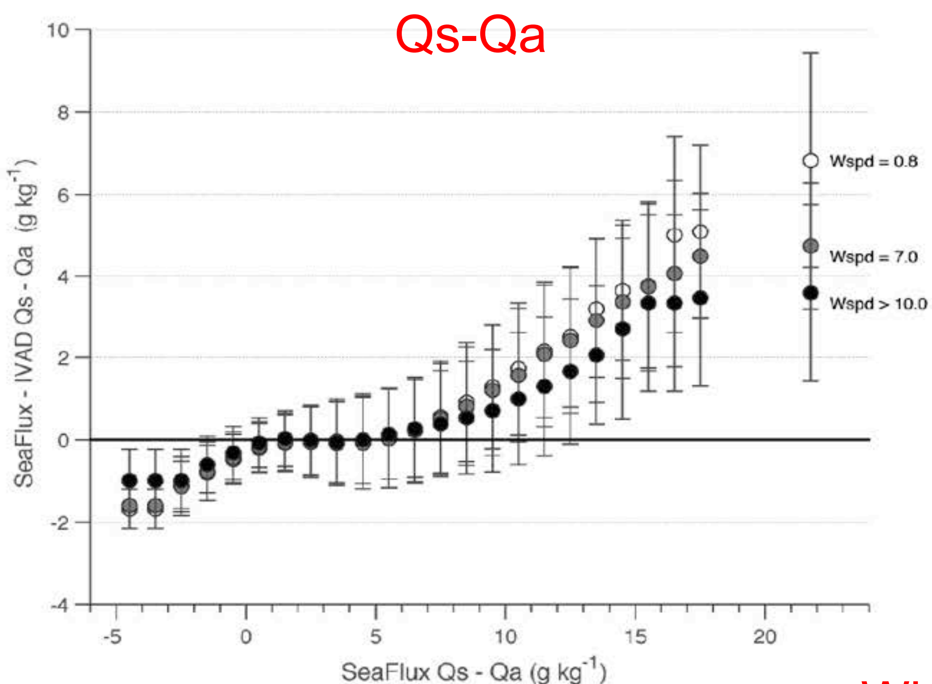
[D. Miralles, work in progress]

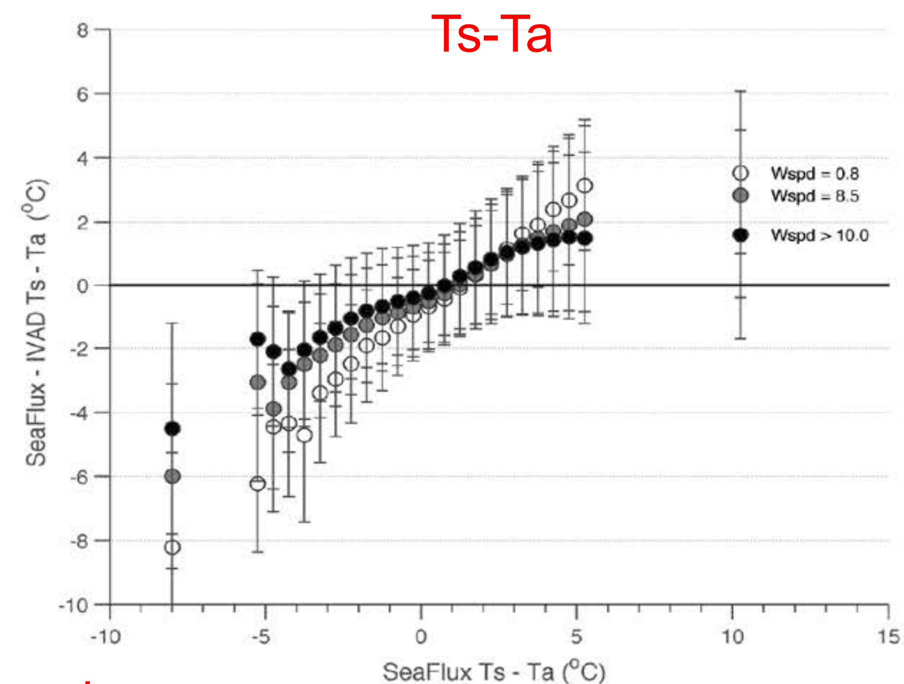
Comparisons with IVAD data (courtesy of E. Kent)

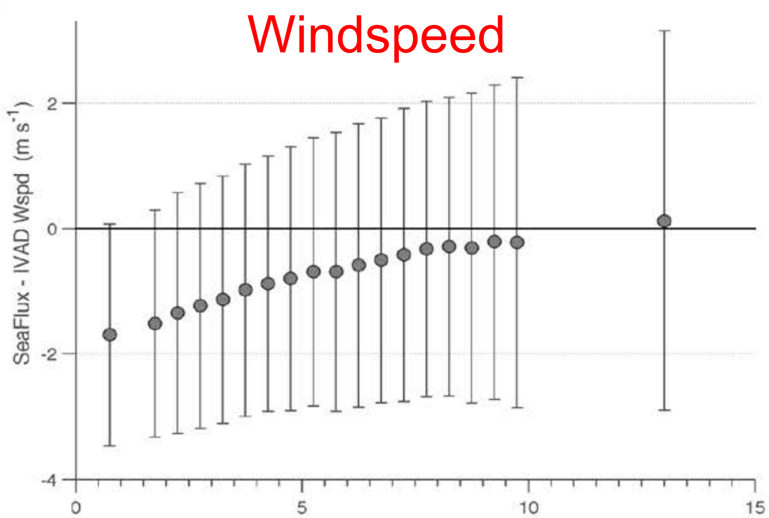


Clayson et al. 2013

Evaluating uncertainty using IVAD data



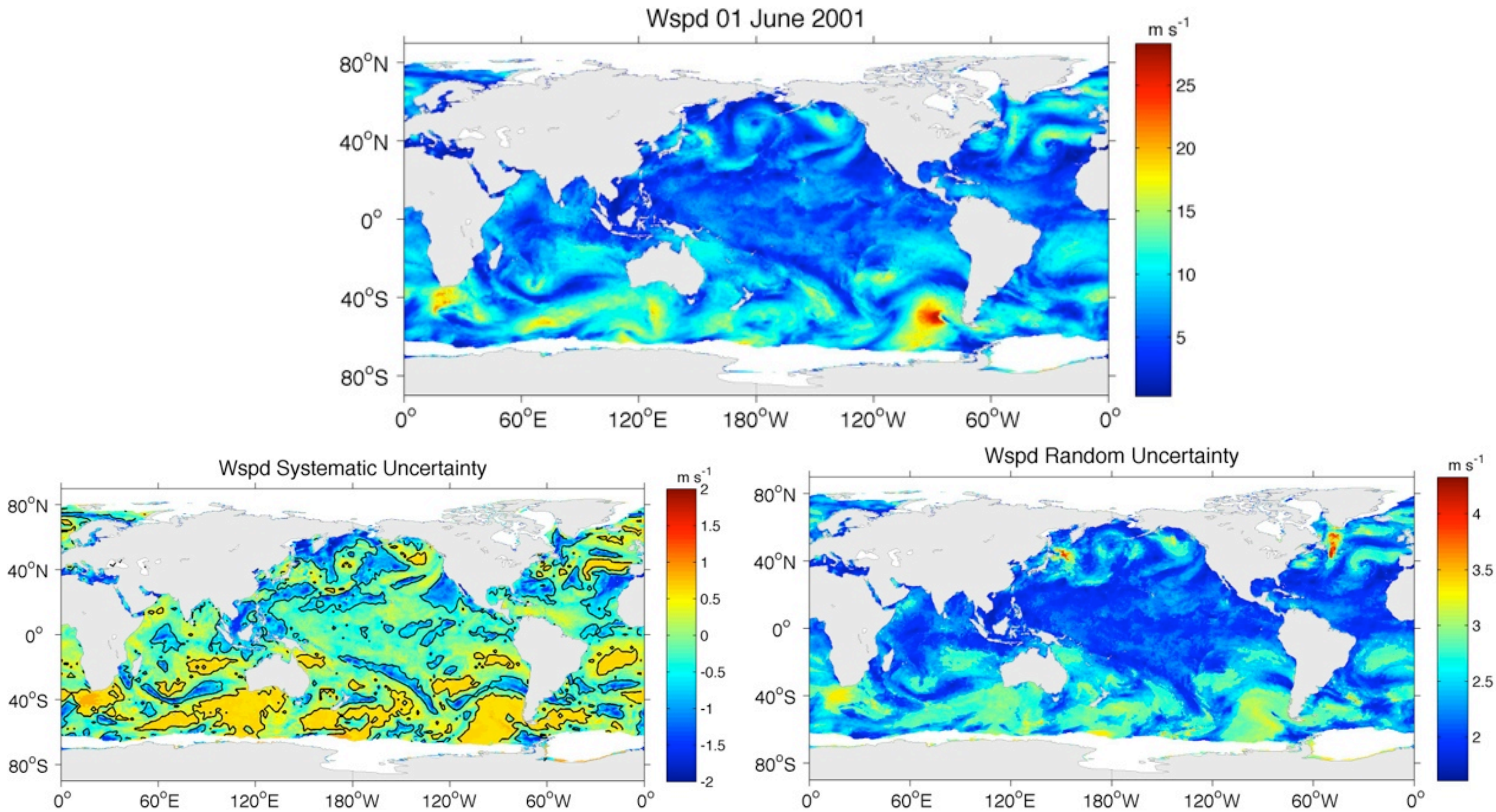




Clayson et al. 2013

$$\sigma_{LHF} = \Big[\left(\rho_a L_v U (Qs-Qa)\sigma_{C_E,sys}\right)^2 + \left(\rho_a L_v C_E (Qs-Qa)\sigma_{U,sys}\right)^2 + \left(\rho_a L_v C_E U \sigma_{(Qs-Qa),sys}\right)^2 + 2r_{(Qs-Qa),U}\left(\left(\rho_a L_v C_E\right)^2 (Qs-Qa) U \sigma_{(Qs-Qa),sys}\sigma_{U,sys}\right)$$
$$+\left(\rho_a L_v U (Qs-Qa)\sigma_{C_E,ran}\right)^2 + \left(\rho_a L_v C_E (Qs-Qa)\sigma_{U,ran}\right)^2 + \left(\rho_a L_v C_E U \sigma_{(Qs-Qa),ran}\right)^2 + 2r_{(Qs-Qa),U}\left(\left(\rho_a L_v C_E\right)^2 (Qs-Qa) U \sigma_{(Qs-Qa),ran}\sigma_{U,ran}\right)\Big]^{1/2}$$

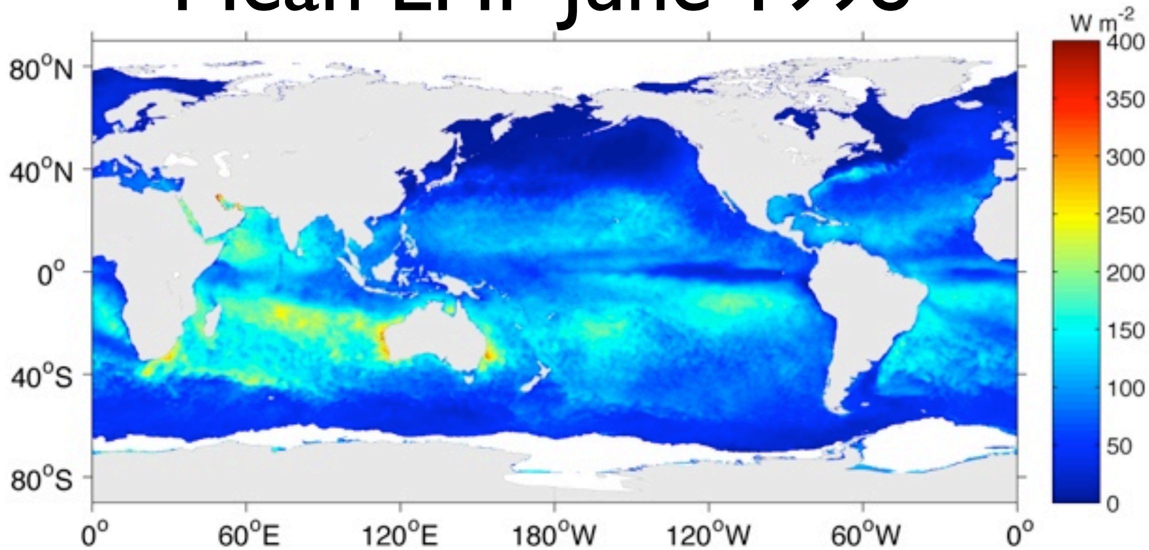
Instantaneous fields



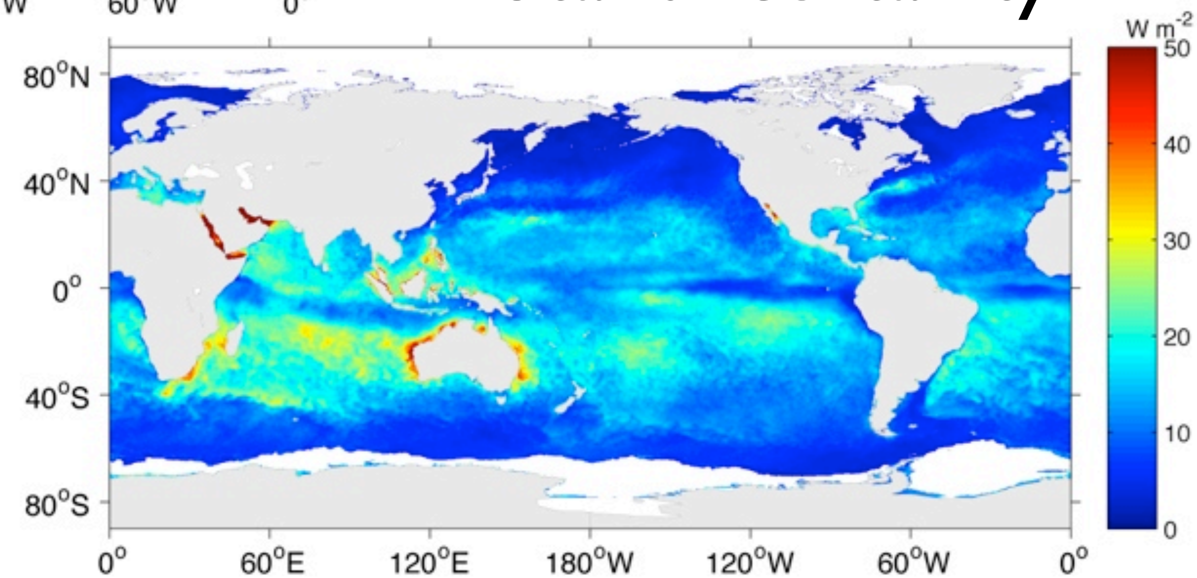
Clayson et al. 2013

LHF monthly uncertainty

Mean LHF June 1998

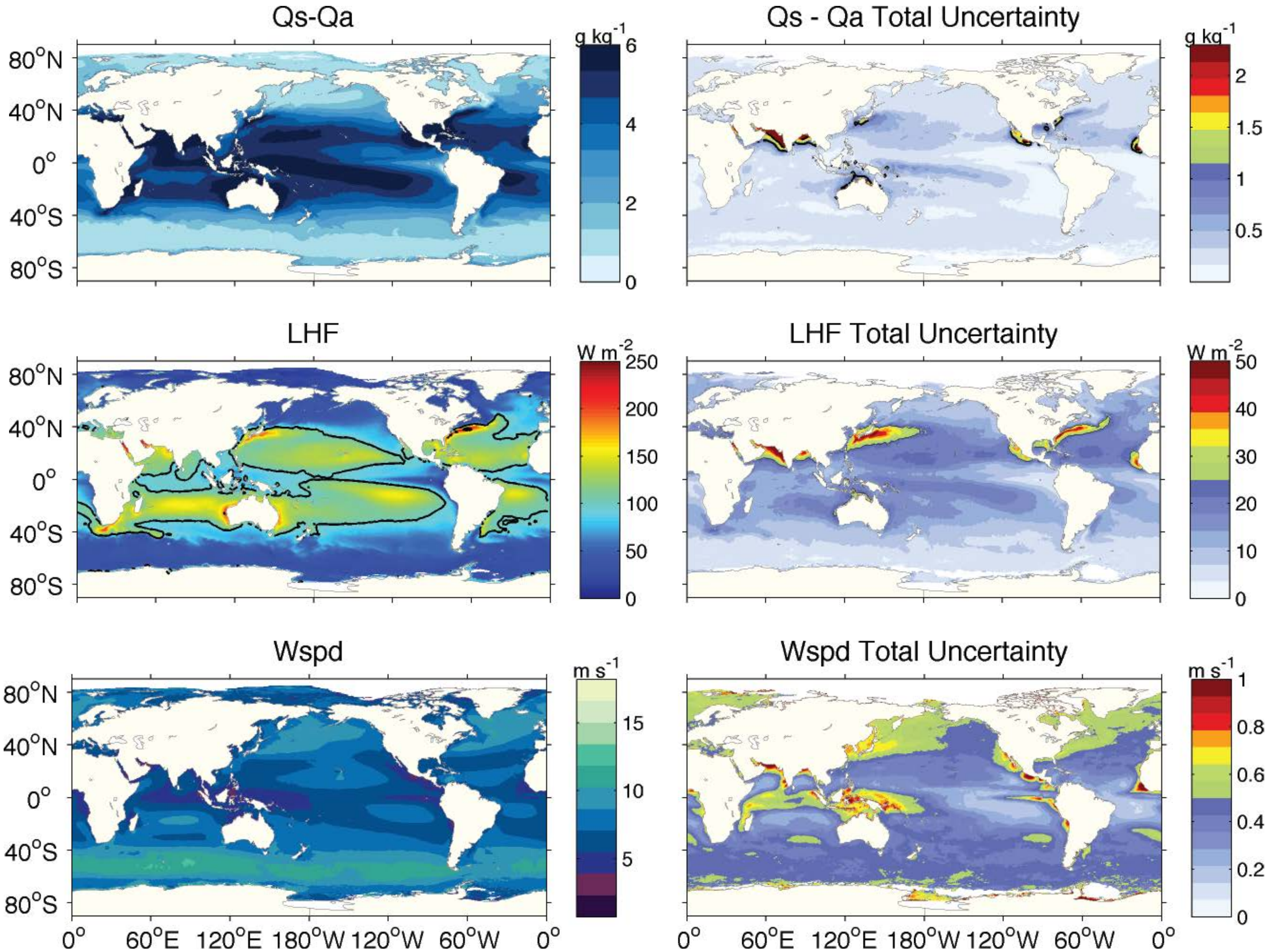


Total uncertainty



Clayson et al. 2013

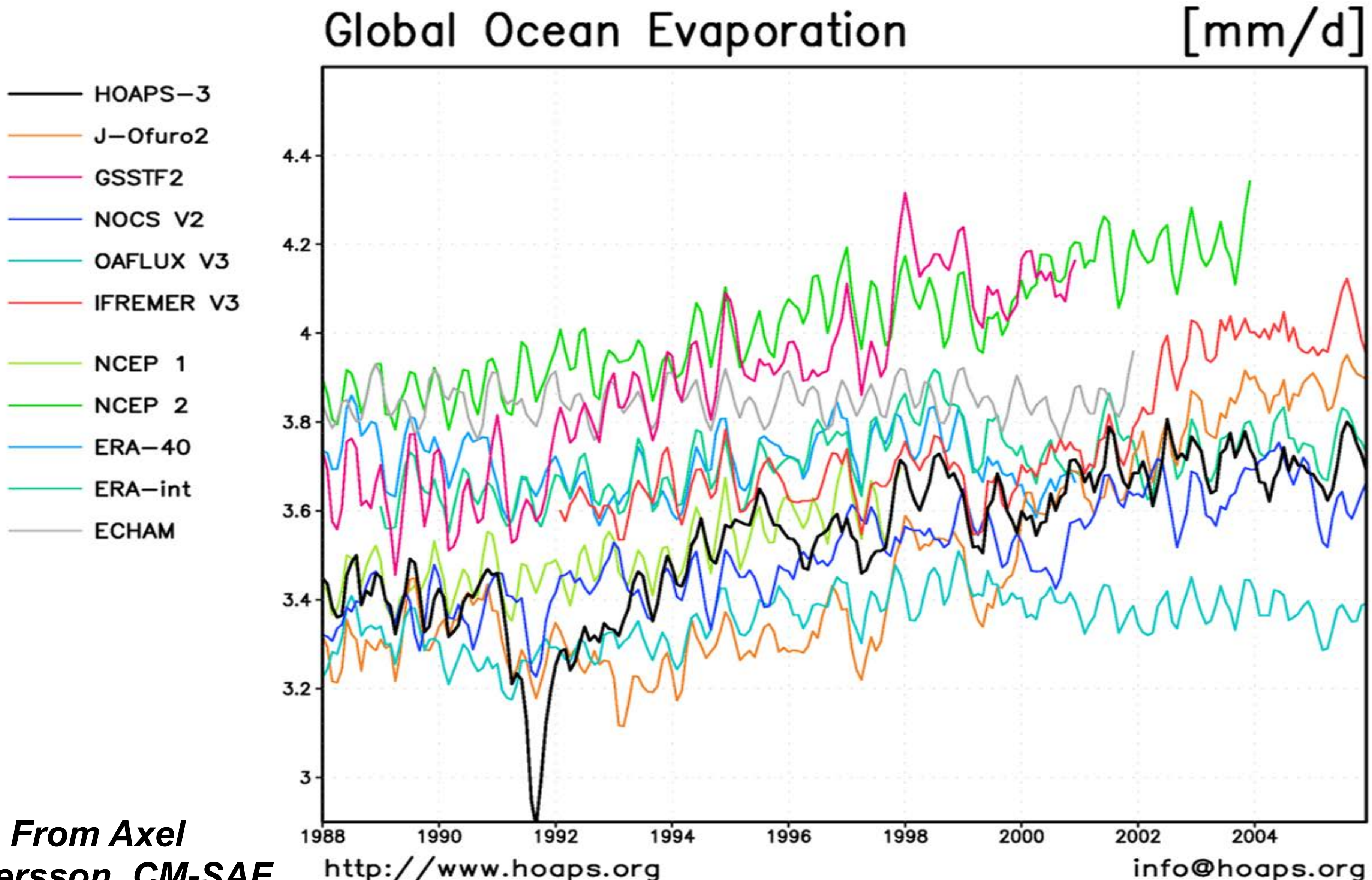
Uncertainty estimates



Variable	Global uncertainty
LHF (W m^{-2})	13.9 (15.4%)
SHF (W m^{-2})	5.7 (32%)
Windspeed (m s^{-1})	0.12 (1.6%)
Qa (g kg^{-1})	0.26 (2.2%)
SST (^{o}C)	0.1 (< 1%)
Ta (^{o}C)	0.01 (< 1%)
Ts - Ta (^{o}C)	0.23 (16.1%)
Qs - Qa (g kg^{-1})	0.15 (4.1%)

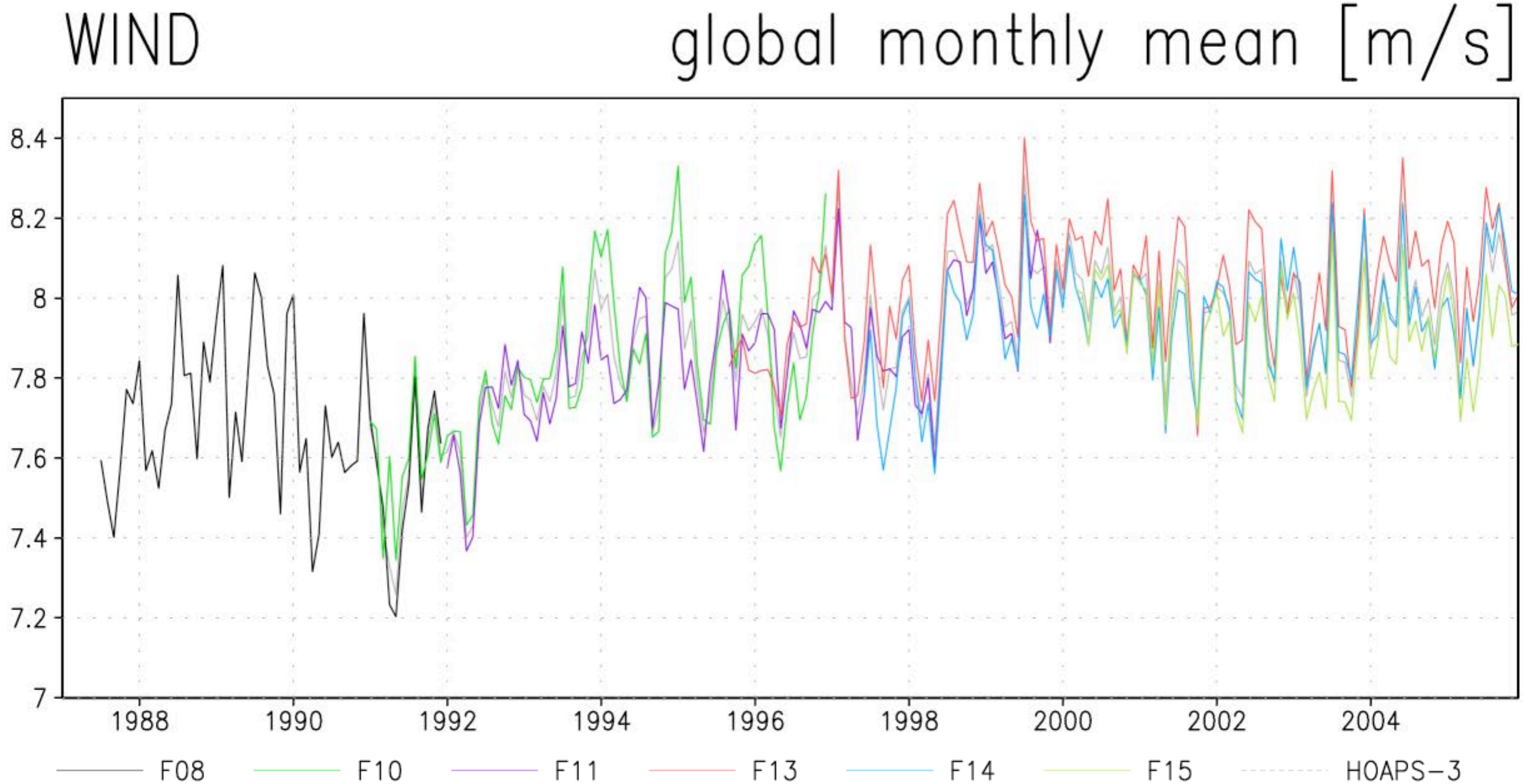
Clayson et al. 2013

Trends in evaporation



From Axel Andersson, CM-SAF

HOAPS-3 Wind Speed

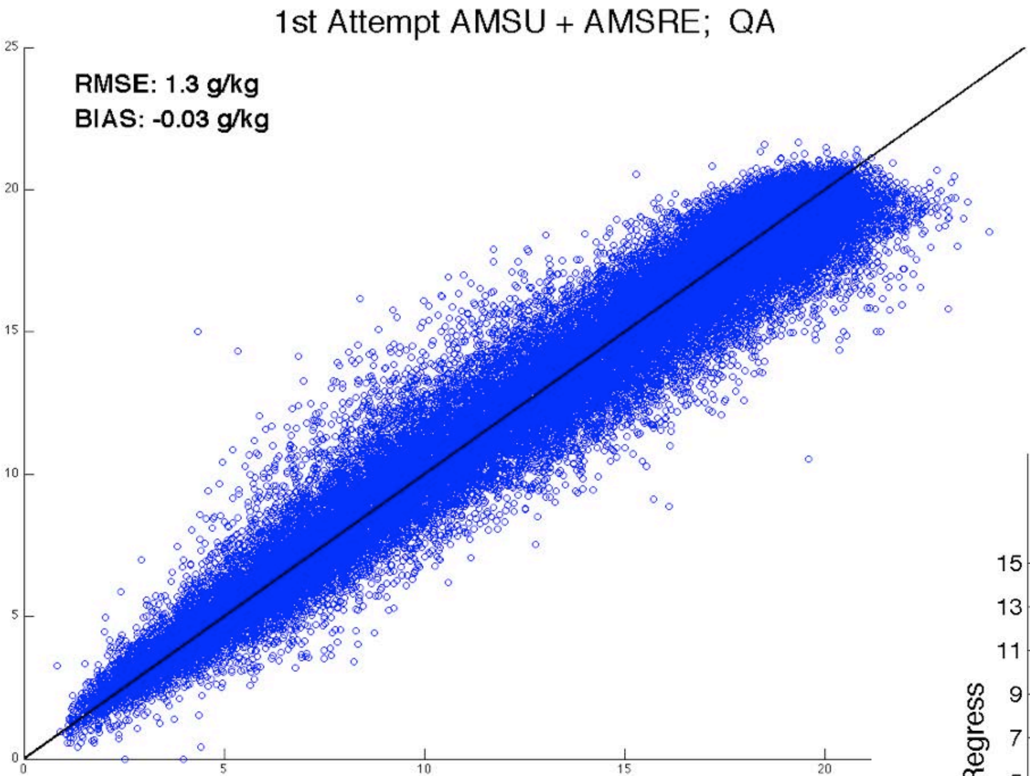


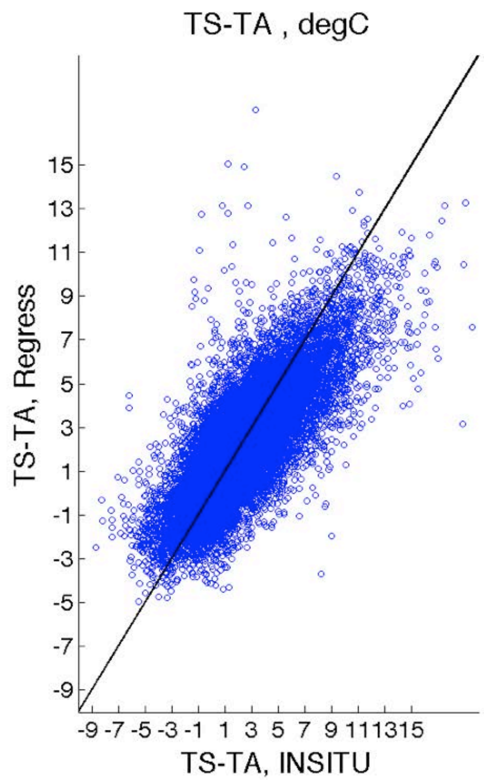
From Axel Andersson, CM-SAF

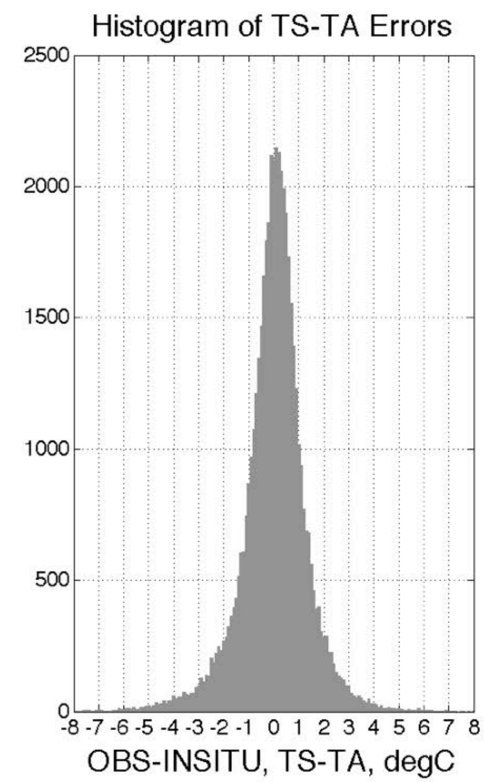
Strategies for Improving Ocean Turbulent Fluxes

- More routine observations: Moorings, or routine ship-board observations of momentum and turbulent heat fluxes
  - Extremes: cold air outbreaks, hurricanes
  - High-latitudes
- More process studies: put together evap, precip, latent heating profiles into some case studies
- Coastal/MIZ processes: how do we resolve coastal processes
- Better calibration: we need to resolve what are appropriate calibrations for multiple uses
- New satellites: Prospect of obtaining momentum, latent heat, sensible heat, radiative fluxes through a well-defined set of sensors, possibly in multi-satellite formation ("Flux Train")
- More global coverage: "missing" events significant problem

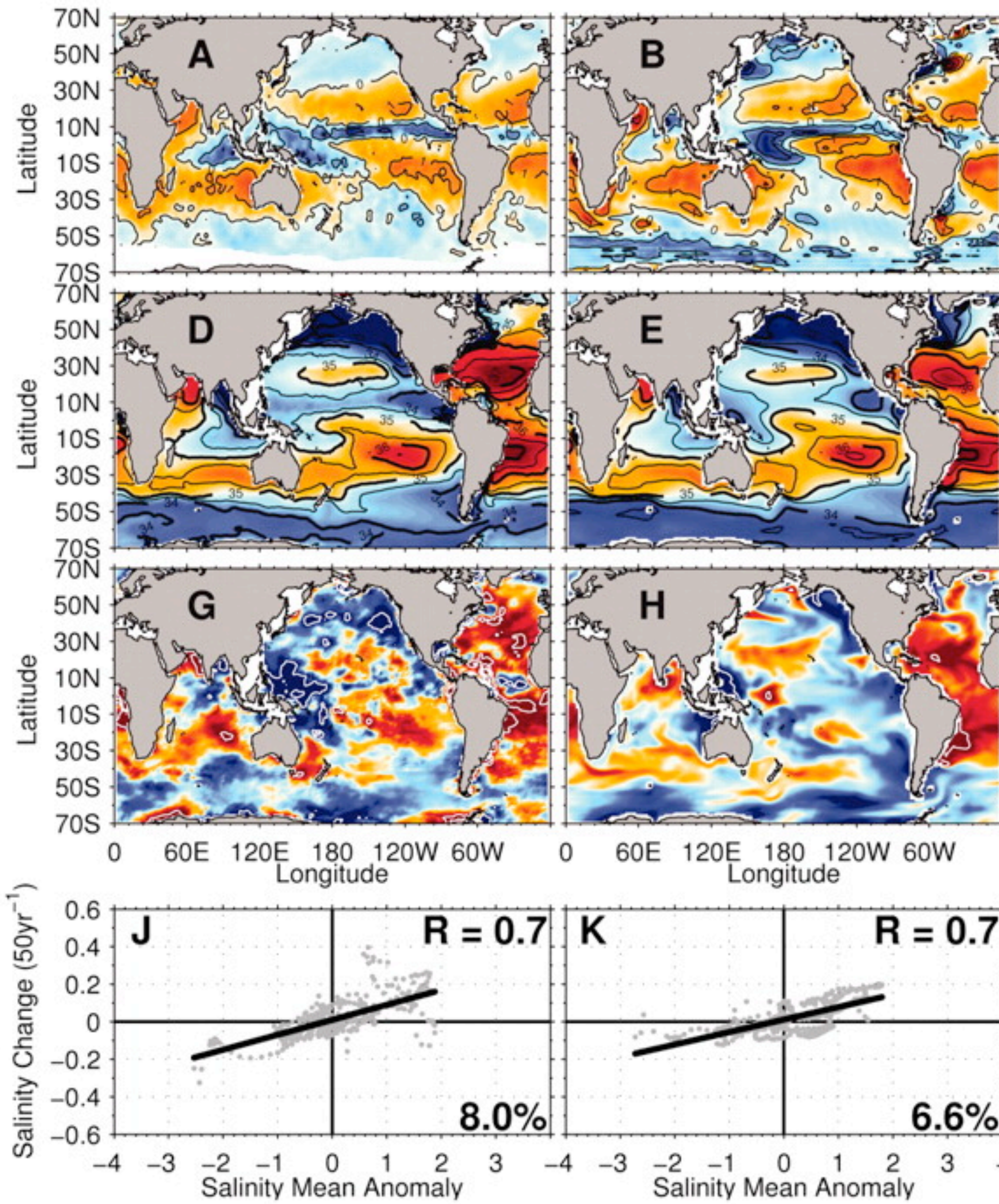
New results: AMSR-E/AMSU







We can look to ocean salinity



Mean E - P

Mean Surface Salinity

Surface Salinity Change

P J Durack et al. Science 2012;336:455-458

Fig. 1 Observed and selected CMIP3 20C3M simulations of surface salinity and water fluxes.

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Strategies for Improving Land Turbulent Fluxes

- Conducting first assessments characterising the uncertainty in the existing global estimates of land surface heat fluxes
- Global annual Qle are in a range of 15 W/m^2 for an ensemble average of ~ 45 W/m^2, a bit larger for Qh
- Progress has been made (a growing number of global satellite-based (diagnostic) estimates) but significant differences can still be observed
- Moving to dataset production: based on experienced gained during the assessments
    - Merged/synthesis dataset [ETHZ]
    - Satellite-based V0 products [PU, UoB, UoNSW, PO]

Strategies for Improving Land Turbulent Fluxes

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Global products of evapotranspiration: the GEWEX LandFLUX Initiative

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Strategies for Improving Land Turbulent Fluxes

Version 0 LandFLUX product to be released October 2013
- requires community involvement –

What are the take home messages:

1. Model performance linked to metric, scale and zone/type
   - require comprehensive evaluation strategy
2. Issue of forcing quality constrains achievable accuracy
   - T_s and u_a present problems (uncertainty modeling?)
3. Influence of seasonality on model response (*not shown*)
   - better performance spring/autumn v's summer/winter
4. No model works every where, every time!
   - an ensemble product/model weighting/new models?